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Project: Development of Runways

Authors: Angeliki Maria Kaplani, Emil Ingeson, Héloïse Venaut, Nedim Curic, Ran Li, Thjis Hillebrand

Non-technical summary

Stockholm Arlanda Airport is the third biggest airport in Scandinavia. The flights land and take-off (LTO) on the three runways that the airport accommodates. However, the existing three runways (two of them being parallel) will not be enough to accommodate all flights in the future (Swedavia AB, 2017c). To be able to support the increase in arriving and departing flights, Swedavia plans to construct a new runway on the North-East side of the airport parallel to runway 1 and 3 (Swedavia AB, 2017c).
Planning and constructing a new runway is an extensive process that could take twenty years and influences the social and physical environment, both directly and indirectly in and around Arlanda.
The environmental impacts of constructing a fourth runway can be divided into seven aspects:

- Noise
- Air quality and climate
- Hydrology
- Geology
- Biodiversity
- Human Health
- Landscape and archaeology

To be able to minimize the environmental impacts, alternatives for location, design, material, and operational methods have been explored. However, not all alternatives have a significant difference on all environmental aspects.

Noise
Noise is paramount when dealing with airports. Except for the location, no other factors significantly influence the noise impact. Location East is discouraged because intensive use of the runway will most likely result in exceeding the noise limitation barriers South of Arlanda. Alternative North causes the least increase in affected housings by noise pollution; it increases the residential building exposed to noise pollution with 10%, in comparison to the 28% more affected residential buildings in the proposed area.

Air quality and climate
Air quality and climate are affected on a spatially larger scale than the other environmental impacts. Consequently, air quality and the climate are equally affected by the positioning choice of the new runway. Looking at the larger scale, the explored locations are in the same general area and the impacts from emissions will not differ greatly by moving the runway from one proposed location to another.
Regarding material use for the runway, concrete is preferred since it releases significantly less carbon dioxide (CO_2) during its lifespan than a runway made of asphalt. Additionally, the impact on climate by emissions from air traffic can lessen if scientific progress is made with increasingly sustainable engines.

Hydrology

The choice of location for a fourth runway will affect the flow of groundwater differently. It mainly depends on the depth of the groundwater in the area. The surface water depends on location, but also change in the climate. An increase in precipitation will increase the surface runoff which increases the load on management as well as rinses of the de-icing chemicals on runways. While an increase in temperature and humidity affects the contaminants that change brings. When temperature increases the need of de-icing chemicals decreases. These chemicals do not solely impact hydrology, but also affect ecosystems that are highly intertwined with the surrounding nature. Wastewater and storm water drainage systems therefore need to be planned and have the necessary dimensions to be able to deal with prognosed changes. Further research is needed for more effective operational methods to be applicable.

Geology

Soil in this area is rich in fluvial sediment, peat and bedrock. Therefore, the location of a new runway will have a substantial influence on the spread of contaminants in the area. The need for drainage and treatment during construction increases in areas rich in fluvial sediment, the opposite is true in areas with bedrock. The latter might present other problems, such as arsenic spreading in dust and water. Using clay and wetlands as heavy metal traps might be an effective use of nature's resources. The proposed location is preferred if dust and water spreading of arsenic can be hindered, this would decrease the natural leakage of arsenic into flora and fauna through water.

Biodiversity

The construction of a new runway will destroy, reduce and fragmentate natural habitat for the local fauna and flora. Any choice of location will deeply affect the local biodiversity and have long lasting and possibly irreversible impacts in the area. However, some locations are impacted less than others in regards to biodiversity. The Northern alternative is such an example. It is the location that is most recommended to minimize negative impacts on biodiversity. Additionally, the impact is connected to the length of the new runway. A longer runway will have a bigger impact while a shorter one will have a lesser impact.

Human Health

As the amount of flight movements increases, Arlanda airport increases its impact on human health in the surrounding region, mainly via noise and air quality. However, since the impact is spread over a large area, which inhabits relatively few people, the impact is estimated to be "minor negative". Regarding noise, the impact on health will be the biggest in the Eastern location. Therefore, this location is dissuaded from a human health perspective.

Landscape and archaeology

Constructing a new runway will have a varying impact on landscape and archaeology, mainly depending on the location and design of the runway. The runway will, regardless the location, transform current forest and agricultural land into industrial looking airport, resulting in a decreasing user value and experienced value, and therefore deteriorate the spatial quality of the area. From an archaeological point of view, locations North and North-East are the least damaging ones because these locations contain less sites with archaeological value.

Icke teknisk sammanfattning

Stockholm Arlanda Flygplats är den tredje största flygplatsen i Skandinavien. Flygplanen landar och startar på de 3 befintliga landningsbanorna. I framtiden kommer dock dessa tre (varav två är parallella) inte tillgodose den framtida ökade flygtrafiken (Swedavia AB, 2017c). För att kunna hantera denna ökning i ankommande samt avgående flygplan, planerar Swedavia att bygga en ny rullbana i nordöstra delen av flygplatsen, parallellt till landningsbanorna 1 och 3 (Swedavia AB, 2017c).
Planeringen och byggandet av en ny rullbana är en omfattande process som kan ta upp till tjugo år. Denna kan påverka den sociala och fysiska miljön, direkt och indirekt, på och runtomkring Arlanda området.
Miljökonsekvenserna vid byggandet av en fjärde rullbana kan delas upp i sju delar:

- Buller
- Luftkvalitet och klimat
- Hydrologi
- Geologi
- Biologiskt mångfald
- Människors hälsa
- Landskap och arkeologi

För att kunna minimera miljöpåverkningarna, har alternativ för lokalisering, design, material samt operativa metoder undersökts. Alla alternativ har dock inte en betydande miljöpåverkning.

Buller
Buller är av väldigt stor vikt när det gäller flygplatser. Bortsett från var rullbanan är lokaliserad, så har andra faktorer endast en mindre påverkan på buller nivån. En rullbana till öster om terminalerna förhindras av att en intensiv användning av rullbanan kommer sannolikt leda till att restriktioner av bullernivåer överskrids i en sydlig riktning. Norra alternativet leder till det minsta antalet hushåll påverkade av en bullerökning med en ökning på 10 %. Detta jämfört med en ökning av 28 % fler påverkade hushåll vid den föreslagna lokaliseringen av rullbana 4.

Luftkvalitet och klimat
Luftkvalitet och klimat påverkas på en mycket större yta än övriga miljöpåverkningar. Därmed kommer luftkvalitet och klimat påverkas lika mycket oavsett var rullbanan placeras runtomkring Arlanda. Alltså, tittar man utifrån en större skala så kommer placeringen av en rullbana inte påverka mängden avgaser avsevärt.
När det gäller material för rullbanan, föredras betong då den släpper ut betydligt mindre koldioxid under dess livslängd än en rullbana av asfalt. Utöver detta så kommer klimatpåverkan av flygtrafik minska om vetenskapliga framsteg görs kring hållbara flygplansmotorer.

Hydrologi
Valet av platsen av en fjärde rullbana kommer påverka flödet av grundvatten olika. Det beror främst på grundvattennivån i området. Ytvattnet beror också på platsvalet, men också av klimatförändringar. En ökning av nederbörd kommer att leda till en ökning av ytvattenavrinning. Detta leder till en ökad belastning av dagvattenhantering samt avspolning av avisningsmedel från landningsbanorna. Medan en ökning av temperaturen och luftfuktigheten kommer att påverka föroreningarna som transporteras av vattnet. Dessa kemiska föreningar kommer inte bara påverka hydrologin, men också ekosystemen som är starkt sammanflätade med den kringliggande miljön. Spillvatten och dagvattenhanteringen behöver planeras samt ha de korrekta dimensionerna för att kunna hantera potentiella förändringar. Framtida forskning behövs för att effektivare operativa metoder ska kunna vara applicerbara.

Geologi

Jorden i detta område är rik på isälvssediment, postglaciala sediment, torv samt urberg. Därmed kommer placeringen av en ny rullbana påverka spridningen av föroreningar i detta område. Behovet av dränering och behandling av spillvatten under byggandet ökar i områden rika på isälvssediment samt postglaciala sediment, motsatsen gäller i områden rikt på urberg. Det senare kan ge andra problem, som spridning av arsenik via damm och vatten. Användning av lera och våtmarker som tungmetallfällor kan vara ett effektivt användande av naturtillgångar. Den föreslagna platsen föredras om damm och vattenspridningen av arsenik kan förhindras. Detta kan leda till en minskning av naturlig urlakning av arsenik till flora och fauna genom vattnet.

Biologiskt mångfald
Byggandet av en ny rullbana kommer att förstöra, minska och fragmentera naturliga livsmiljöer för den lokala faunan och floran. Varje val av placering kommer ha en långvarig och potentiellt irreversibel påverkan i området. En del placeringar kommer påverka mindre än andra när det gäller biologisk mångfald. Det norra alternativet är ett sådant exempel, placeringen är att föredra när det gäller att minimera negativa påverkningar på biologiskt mångfald, konsekvenserna kan knytas ihop med längden av rullbanan. En längre rullbana kommer att ha en större påverkan medan en kortare kommer att ha en mindre påverkan.

Människors hälsa
När flygtrafiken ökar, kommer Arlandas påverkan på människors hälsa att öka, främst genom buller och luftkvalitet. Eftersom dessa påverkningar sprids över en större yta, som har färre invånare, kommer konsekvenserna bedömas som “mindre negativa”. Bullerpåverkan på människors hälsa kommer att vara som störst i det östra alternativet vid placering av en ny rullbana. Därför avråds detta alternativ utifrån ett människohälsoperspektiv.

Landskap och arkeologi
Byggandet av en ny rullbana kommer ha varierande konsekvenser på landskapet och arkeologin. Huvudsakligen beroende på placeringen och designen av rullbanan. rullbanan kommer, oavsett val av plats, omvandla skogs- och jordbruksmark till industriell mark. Detta resulterar i en minskning av användarvärdet och upplevelsevärdet, och därmed försämras den rumsliga kvalitén av detta område. Från en arkeologiskt ståndpunkt är norra och nordöstra alternativen minst skadliga tack vare att dessa områden innehåller mindre arkeologiskt värde.

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2.1 Introduction

Stockholm Arlanda Airport is the third biggest airport in Scandinavia with more than 300.000 flights per year. The flights are landing and taking-off on the three runways the airport accommodates. However, the existing three runways (two of them being parallel) will not be enough to take in all flights in the future. Swedavia, the state-owned company that manages and operates Arlanda airport, expects an increase of 10 million passengers until 2035 and possible even up to 70 million passengers in the next 50 years (Swedavia AB, 2017c).

To be able to accommodate the increase in arriving and departing flights, Swedavia plans to construct a new runway on the North-East side of the airport parallel to runway 1 and 3. Constructing a new runway is a big process and therefore, according to the Swedish Environmental Code, an Environmental Impact Assessment (EIA) needs to be executed.

The purpose of the EIA is to assess the environmental impact of the construction and operation of runway 4 and consider possible alternatives from environmental and human health perspectives. The results from the EIA highlight the significant environmental impacts. On top of that, the environmental baseline, alternatives and cumulative effects are analyzed here. The initial plan is based on the Draft Masterplan of Swedavia (Swedavia AB, 2017c).

This EIA is written in three parts. In the first part, the project is explained and the current status of the physical environment around Arlanda is presented. The second part is the impact analysis, in which all significant impacts are highlighted. In the third part, the impacts are considered in a broader perspective, using cumulative effects, ecosystem services, and one part is dedicated to elaborate about uncertainty in the impact analysis. The report gives a recommendation for the construction and operation of a new runway in the end. It should be noted that in every case and impact, the worst case scenario is taken into consideration.

The vision of Swedavia AB (2017c), regarding amount of passengers, flight movements and when it will happen are in this chapter treated as a prognosis.

2.2 Current situation and proposed activities

Chapter 2.2 describes the current situation regarding the runways at Arlanda airport together with the proposed activities to construct a new runway. First, an overview is presented with the current situation regarding the 3 runways. From the current situation, the environmental baselines are established using the most recent data available. Conclusively, the proposed project for a fourth runway is analyzed and split into activities, which lead to impacts.

2.2.1 Current situation

Arlanda airport has three landing and take-off runways serving international flights to 181 destinations (Swedavia, 2017a). The biggest runway, able to handle the heaviest landing and take-off aircraft, is the Runway 1 (01L/19R) located to the West of the terminals. It is made of concrete surface measuring 3.300 m length and 45 m width. Runway 2 (08/26) is located to the North of the terminals and has a concrete surface of 2.500 m length and 45 m width. It is the only platform oriented West-Eastward, whereas Runway 1 and 3 are North-Southward. Runway 3 (01R/19L) has an asphalt surface of 2.500 m length and 45 m width and is located on the East of the terminals. Runway 2 and 3 can work independently from each other (Airportguide, 2017).

In winter, planes need to be de-iced before they can take-off. Runway 3 is the only one equipped with a de-icing area.

Table 2.1: Current state of runways

	Name	**Size (meter)**	**Material**
Runway 1	01L/19R	3.300 x 45	Concrete
Runway 2	08/26	2.500 x 45	Concrete
Runway 3	01R/19L	2.500 x 45	Asphalt

In 2016, 216.685 flight movements were registered at Arlanda Airport, making it the third largest airport in Scandinavia (Swedavia AB, 2017g). Arlanda can handle all types of aircrafts, even an Airbus A380, the world's largest passenger airliner on runway 1.
The airport facilitates commercial aircrafts, cargo and business jets 24 hours per day. In 2016, 68% of the flight movements was during the day (06.00-18.00), 24% during the evening (18.00-22.00), and 9% during the night (22.00-06.00). Even during snowfall, the airport strives to stay operational (Swedavia AB, 2017b).

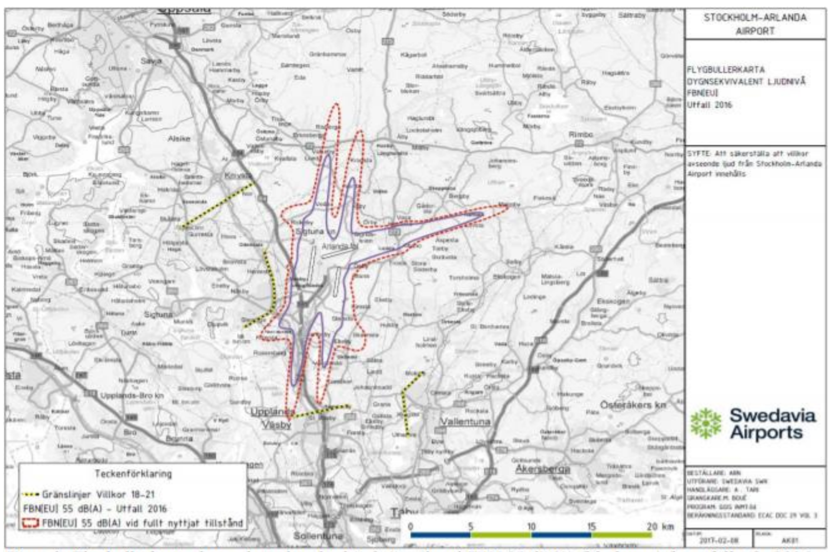
2.2.2 Environmental baseline

The description of the environmental baseline includes the establishment of the present state of the environment in the absence of the project. The selected environmental aspects concern the noise, air quality and climate, hydrology and geology, biodiversity, human health and landscape and archaeology.

2.2.2.1 Noise

The biggest producers of noise connected to an airport are the airplanes. The highest levels of noise are normally perceived during landing and take-off, depending on the type and model of aircraft the noise perceived on ground level can vary. The perception of these noise levels also varies with proximity to the airplanes. As the distance increases, the perceived noise on ground level decreases. Consequently, the noise is loudest in the direct vicinity of the airport. The harmful levels of noise have been set to be higher than 55 dB. It is also important to remember that (to a certain extent) sound starts being harmful if one is exposed to it perpetually or repeatedly (Stansfield *et al*., 2003; Swedavia AB, 2017c).

In 2016, an area of 74 km[2] had noise levels greater than 55 dB on ground level (see Figure 2.1). At the same time, the area had 1 207 residential buildings, where 1 886 inhabitants were living in (Swedavia AB, 2017c). However, in 2016 Arlanda airport was not operating at full capacity, this would result in an affected area of 133 km2 and 1 233 residential buildings. (Swedavia AB, 2017c)



Figur 9. Flygbullerkarta dygnsekvivalent ljudnivå. Beräknad FBN 55 dB(A) (lila kurva) för utfallet år 2016 tillsammans med gränslinjer för villkoren visas i gula streckade linjer. I figuren visas också FBN 55 dB(A) vid fullt nyttjat tillstånd (röd, streckad kurva).

Figure 2.1: Noise levels & restrictions (Swedavia AB, 2017c)

2.2.2.2 Air quality and climate

One of ICAO's Environmental Protection Strategic Objectives is to limit or reduce the impact of aircraft engine emissions on local air quality (ICAO, 2017a). Air pollution caused by the airport is a significant concern for local governments. According to IPCC statements (2013), aviation today accounts for appropriate 2% of the global CO_2 emissions. In Sweden, aviation is responsible for 4 - 5% of its total fossil CO_2 emissions (Swedavia AB, 2017e).

Air traffic and road traffic are the principal producers of emissions at the Arlanda airport. Air pollution levels at the region of the airport correspond to those produced in a mid-size Swedish metropolitan area (Swedavia AB, 2017e). Air pollution is mainly caused by aircraft engines including CO_2, nitrogen oxide (NO_x), sulfur dioxide (SO_2), hydrocarbons, soot and other particles. In specific locations, such as in the South of Arlanda, NO_x and fine particles exceed the environmental quality standards. According to the Arlanda environmental report (Swedavia AB, 2017b), from 2014 to 2016, the annual NO_x emissions increased from 871 tons to 949 tons and CO_2 emissions increased from 208 396 tons to 221 204 tons respectively. There is no significant increase of SO_2 and non-methane hydrocarbon (NMHC).

Air pollutants spread in the atmosphere depends on the wind direction and air temperature. Therefore, it is difficult to evaluate how pollutants affect the surrounding areas. Previously, Arlanda airport had a cap on CO_2 emissions in its environmental permits. This meant that CO_2 emissions emanating from aircrafts, ground transportations and heating in year 2016 should not exceed the levels produced in 1990 (Swedavia AB, 2017e). However, this policy was abandoned and replaced with an action plan aimed at reducing emissions of CO_2, NO_x and other particles (Swedavia AB, 2017c). Compared to 1990, the number of passengers and emissions from vehicular traffic have increased. Nevertheless, CO_2 emissions from air traffic has decreased.

2.2.2.3 Hydrology and Geology

The airport is surrounded by agriculture and old farmland, which leads to an excess of nutrients nitrogen and phosphorus compounds. These contribute to an eutrophication and can increase the total organic carbon (TOC). TOC is the total amount of organic compound that is available to decay into CO_2 and water (H_2O). No measurements indicate high concentrations when comparing to limits according to less sensitive land use standard created by Naturvårdsverket (Swedish Environmental protection agency) in this area (Swedavia AB, 2017b).

Arlanda airport is located in the vicinity of Stockholmåsen, an esker consisting of mostly glacial fluvial sediment. Around runway 1, there is mainly sandy till and clay. Runway 2 is in an area with mainly postglacial sand and clay and the esker itself. Runway 3 is located in an area of mainly peat, sandy till and the esker. For detailed information look at Figure 2.2.

The Märstaån region transports its surface water with contaminants and (partly its groundwater) to lake Mälaren. From Halmsjön a ditch transports PFAS to Sigridsholmssjön, which flows to Fyrisån (see Figure 2.3). An older map from Sweco (2002) is attached in the appendix (Figure 2.11). The highest PFAS value can be found at the old fire training site at Kättstabäcken, West of runway 1.

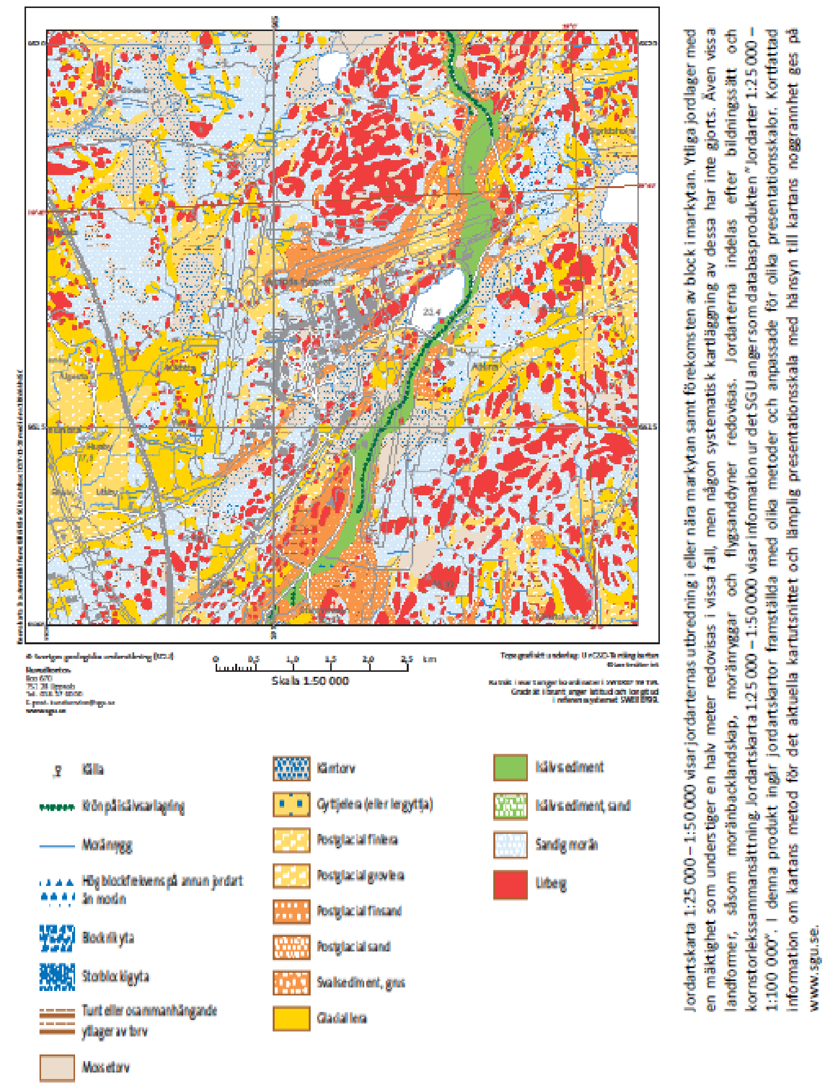


Figure 2.2: Soil map. (SGU, 2017c)

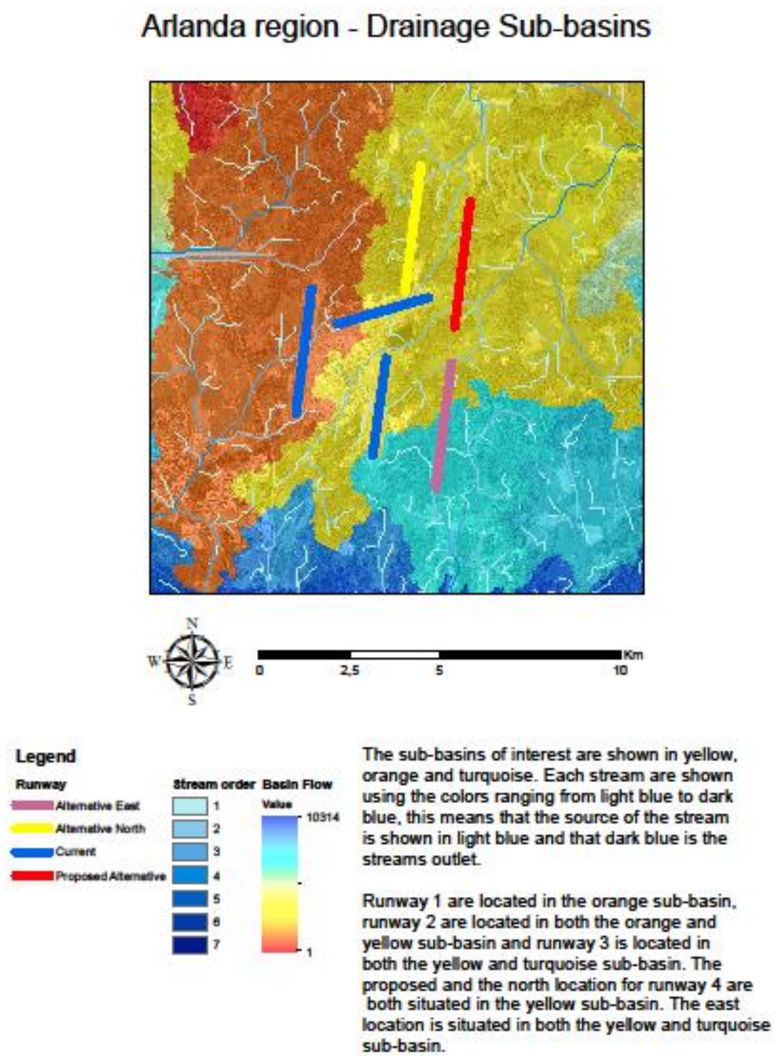


Figure 2.3: Surface water sub-basins of the Arlanda region. (Created using DEM from SGU)

Storm water is collected and transported by various ditches and treated in internal treatment plants before discharged into Märstaån (see Appendix I, Figure 2.9). In some parts, due to a tunnel between Halmsjön and Halmsjöbäcken, the flow does not go Northward towards Halmsjön. Instead, it goes Southwest towards Märstån, as opposed to what is shown in figure 2.3. Therefore, the surface water flow towards Sigridsholmssjön has decreased. This lead to the decrease of lake Sigridsholmssjön:s size has decreased. In 2016, the brook Kättstabäcken contained the highest concentration of TOC 26.3 mg/l (39% of the total load from this area). The waterway from Halmsjön to Broby had the highest oxygen concentrations, implying that it had low TOC levels.

Propylene Glycol (C3H6(OH)2) is used to de-ice the aircrafts on designated locations near the terminals. 10% of the used glycol is collected at terminals and hangars (via sewage pipes, shown in Appendix I, Figure 2.10), leading the de-icing chemicals to the internal treatment plants. It is then sent off to Käppala sewage plant at Lidingö. However, 21% of the de-icing chemicals end up in the storm water (Swedavia, 2017b). The rest, ca 69%, is collected during cleaning by vacuuming the residue and reused.

The internal treatment plants also collect oil spill and metal components (for example cadmium (Cd), highly toxic to both flora and fauna (Nason, 2014) and chromium (Cr)). Concentration of metal particles and TOC have decreased compared to 2015. The total amount of oil that ended up in both wastewater and storm water has increased since 2015. Oil and metals that are collected by filters are transported by SUEZ (a waste recycling company) to Vallentuna municipality (Swedavia AB, 2017b).

The groundwater surrounding the Northern part of runway 1 has increased levels of potassium ion (K+), which is due to usage of potassium formate (HCOOK). The groundwater inside the esker has PFAS concentration above the limits set by SGI for groundwater (Swedavia AB, 2017b).

Groundwater moves South-East towards Märstaån and North-East towards Sigridsholmssjön (dark blue arrows), as can be seen in Figure 2.4.

The annual flow of Märstaån in 2016 was half of what it was in 2015. In 2016, the annual flow was 5 204 000 m3, which is low even compared to the measured yearly flows between 2005-2016. Because of the change in flow: the concentration and mass of TOC, total amount of nitrogen compounds (Tot-N) and total amount of phosphorus compounds (Tot-P) should be taken into account. A high TOC is a direct result of eutrophication due to the use of de-icing chemicals as well as fertilizer use outside of the airport. Fertilizers are only increasing the concentrations of Tot-P and Tot-N already dissolved in the water around Arlanda. When oxygen is low, organic compounds will use up nitrogen compounds to be able to decompose (Dunalska, 2011), this could destroy ecosystems.

According to Naturvårdsverket (in Swedavia AB, 2017b), TOC concentrations have increased, even though the total mass has gone down due to a lessened use of de-icing chemicals. Mass and concentration of Tot-N and Tot-P has decreased due to eutrophication processes and lower water flow. The inflow from agriculture has been stable and has not changed due to a consistent oxygen level. Nevertheless, this will decrease when it is consumed in microbial processes that decompose organic material (if oxygen concentration is low). On the other hand, TOC has not decreased in concentration even though the mass has decreased. This could be a result of a decreased inflow of oxygen, which is needed to decompose organic material (e.g. decrease the TOC value) (Swedavia AB, 2017b).

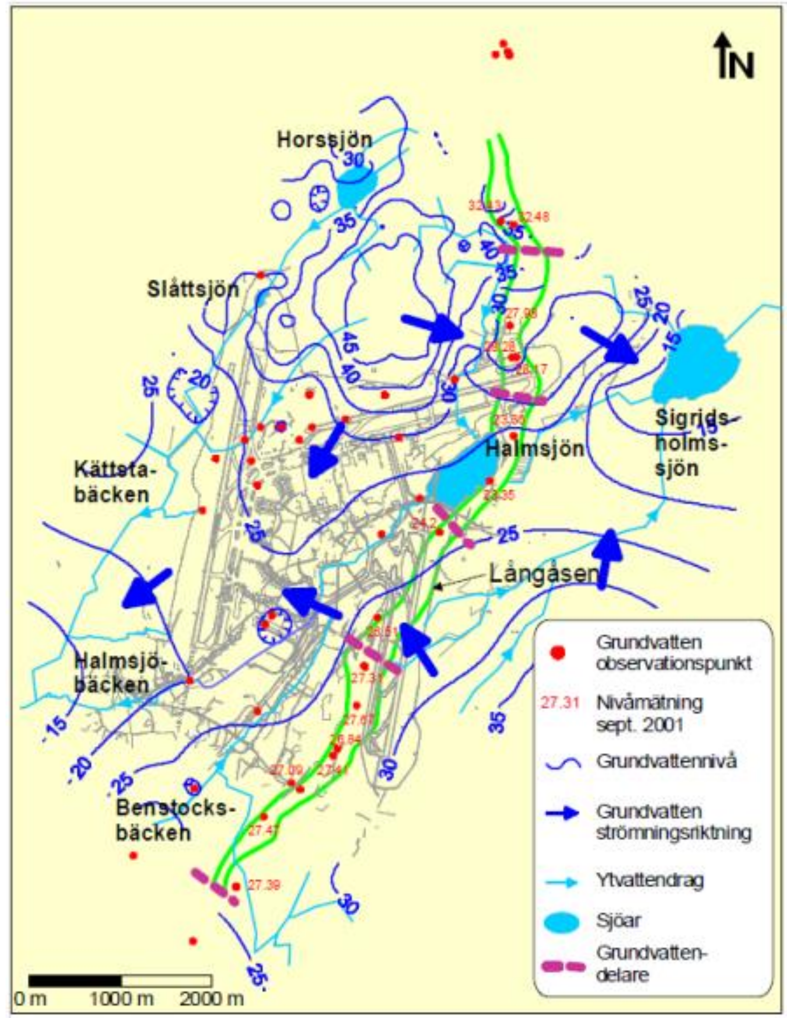


Figure 2.4: Groundwater movement map. (Sweco, 2002)

Measurements show that lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn), were well below the limits set by Naturvårdsverket. Apart from arsenic (As) and uranium (U), every metal was also below the standards set by Havs och Vattenmyndigheten (HaV). These are deemed as natural. PFOS was measured to be above the acceptable levels for surface water, between 110 and 380 times higher when compared to the standards set by HaV (this is not due to natural causes); 72, 200 and 250 ng/l compared to 0.65 ng/l (Swedavia AB, 2017b).

The treatment of Halmsjöbäcken, which collects storm water from runway 2 and 3, seemed to have no problem as it continues to have low concentrations of both TOC, Tot-N and Tot-P. However, Kättskabäcken has problems of high TOC values as it collects storm water from runway 1 as well as surface water from two lakes North of runway 1 (Swedavia AB, 2017b).

2.2.2.4 Biodiversity

The esker Stockholmsåsen is characterized by the presence of sand and gravel around Arlanda airport. The sandy substrate is favorable for a particular type of vegetation and wildlife that has been present for centuries and still thrives. Some trees can exceed an age of 300 years. Looking at it from an ecological point of view these trees represent a great value.

Additionally, the Ekologigruppen identified 74 valuable areas, among them 22 areas were considered as having a major regional interest or higher (Ekologigruppen AB, 2010).

The remaining environment surrounding the airport is characterized by coniferous forest, wetlands and peatlands in the form of mosses and marshes. There are some areas that are maintained as open grassland and pastures.

Twelve different types of habitats have been identified in the area which are protected by the EU habitat directive (Ekologigruppen AB, 2010).

Within them, more than 10 species are listed as having special protection within the EU Birds Directive, as well as 55 red-listed species that are considered as threatened or near threatened at a national scale. Among the red listed, 19 species are from the fungi genus, 15 are bird species, 12 are vascular plants and 2 are beetle species.

The grass around the runways represents a particular ecosystem of open lands because of the strict management procedure of the lawn. Here some species can find their place such as the endangered species Field Gentian (*Gentianella campestris*). Its largest population in Sweden is located at the airport with more than 7,000 individuals identified (Lennartsson, 2015).

The biodiversity is affected by aircrafts that can collide with animals. Bird strikes is a cause of death for birds. They collide with planes mainly during landing and take-off. According to the Swedish Civil Aviation Authority (2006), this represents the second most important reason of plane incidents. The highest rate of collision occurs during the migratory period in August. The frequency of collisions has been estimated at 7.6 collisions per 100,000 aircraft movements. 85 % of bird strikes occur during the landing and take-off of planes below 800 feet (CAA, 2001). The likelihood of collision is higher with the presence of a lake close to the airport, since it provides a place of nesting or feeding for birds and increases the movements around the lakes (SCAA, 2006). The likelihood of bird strikes is also dependent on the species living in the area, the influencing factor being their weight and flying pattern which reduces their capacity to avoid a plane on a collision course with it.

There is also a risk of collision with terrestrial animals. Animal strikes on runways or roads directly reduces the number of animals in the area, which results in reducing the biodiversity of the local environment (AEF, n.d.). A team of professional hunters works at Arlanda airport to prevent animals entering the airport and to make the airport as unpleasant as possible for the animals (Olsson, 2017).

The lights on the runways can also negatively affect animals. It attracts insects and their predators directly to the runways. Once next to the source of light, birds may circle it, become disoriented and exhausted, becoming vulnerable to strikes. Light pollution also has a negative impact on animals concerning their daily rhythm, sleeping and hibernation (AEF, n.d.).

Noise represents a significant impact on the biodiversity of the surroundings too, it reduces the density of animal population because of the disturbance it creates. It can reduce the success of animal breeding, affect their migration patterns, and affect their communication (AEF, n.d.). Noise is also a source of stress and fear (RDU, n.d.). Conclusively, animals are disturbed by the movement and activity created by the presence of an airport. This disturbance can affect their migration, reproduction and life patterns.

2.2.2.5 Human health

Chapter 9, Section 3 of the Swedish Environmental Code states that '*Detriment to human health' shall mean any disturbance that is liable to have adverse effects on health in medical or hygienic terms which are not minor or temporary*" (SFS 2000:61). The construction and operation phases of runways in airports leads toward human health issues.

The most significant environmental concerns in airport developments are noise and air quality (Sahrir *et al*., 2014). These impacts affect the human health both inside the airport (especially the workers on runways) and in the surrounding landscapes and cities (Märsta, Brista and Upplands Väsby).

At an airport, a large amount of noise is produced by the planes. The residents as well as workers near and in the airport are affected by it. Even though the greatest noise impact is within the airport vicinity, disturbances due to aviation noise can occur due to arriving and departing flights as well as overflights further away.

According to Kaltenbach (2008), outdoor aircraft equivalent noise levels of 60 dB during the daytime and 45 dB at night are connected to increased incidences of hypertension. Furthermore, under an extensive review of literature, Swift (2010) concluded that noise exposure in a population will increase heart disease and hypertension, especially with nighttime noise exposure. Additionally, Stansfeld *et al*. (2003) states that there is a connection between noise and hypertension, based on occupational and environmental studies. Community studies do not relate intensively noise and cardiovascular diseases (Stansfeld *et al*., 2003). Also, noise modifies social behaviour and causes annoyance (Stansfeld *et al*., 2003).

Air pollution is a known risk factor for respiratory and heart-related conditions. According to Schlenker *et al.* (2014), there is a relation between levels of CO and hospitalization rates for respiratory and heart-related issues. Especially, asthma cases are likely to increase.

Accounting for the above information, the human health impact in constructing and operating a runway in Arlanda airport is considered to be a cumulative effect, depending on the air quality and the noise levels. Although, according to Swedavia, the last time that there were complaints from the surrounding cities concerning noise was in 2008 (Olsson, 2017).

2.2.2.6 Landscape and archaeology

The existing runways of Arlanda airport are located North, East and West of the airport terminals. The runways lie within a mosaic of natural, industrial, residential land and infrastructure. On the South and West, industrial areas and infrastructure are dominant, while the airport on the North and East nature and residence predominate.

Figure 2.5: View of airplane from forest (Hillebrand, 2017)

Air traffic can be seen as it flies over the Arlanda region when it departs from or arrives at the airport. These views are therefore transient, short of duration and always at varying distances. Patterns in flight routes are rarely constant, the reason being that flights are currently spread over the two parallel runways (1 and 3) and the perpendicular runway (2) to release the areas affected by the parallel runways from impacts of air traffic.

Visual impacts from the runways are limited, since the runways do not have high built structures. On the other hand, the uncovered grass fields that accommodate the runways do present a lack of vegetation in the area, which can be seen from the roads directly adjacent to the runways.

Archeological sites in the Arlanda region are interesting and not yet entirely explored. According to Riksantikvarieämbetet, the Swedish National Heritage Board (2017) not all archeological sites have been researched and artifacts from the Stone Age, Bronze Age, and Iron Age are expected to be found in the area.

2.2.3 Proposed activity

The Arlanda airport is developing in order to handle the increasing number of passengers. Swedavia, projected 40 million passengers by 2040 and plans to construct a new runway (a fourth one) in order to meet their passengers' capacity (Swedavia AB, 2017c). There is a possibility of a fifth runway in the far future.

Assumed is that the plan for the fourth runway involves constructing a new runway on the North-East side of the airport. The runway is planned to have a length of 3.300 m, a width of 45 m and is to be made of concrete. Constructing a new runway on Arlanda airport involves a series of activities that result from this plan. These activities can be divided into two phases; construction and operation activities. Activities in both phases have impacts that need to be assessed in order to identify how they affect the environment. Below two lists are presented with the activities and the aspect of the environment they are most likely to impact. The lists below are indicative and impacts are further analyzed in chapter 4.

Table 2.2: Activities and impacts in construction phase

Activity in construction phase	**Impact**
Transforming landscape	Biodiversity, hydrology, visual, archeological
Usage of machines	Hydrology, geology, noise, air pollution and human health
Soil excavation	Geology, groundwater, visual, archeological
Constructing foundation	Geology, groundwater, surface runoff
Fencing	Biodiversity, fragmentation, visual
Grass around runway	Biodiversity, water infiltration
Disposal of construction material	Hydrology, geology, vegetation, visual

Table 2.3: Activities and impacts in operation phase

Activity in operational phase	**Impact**
Flight movement (landing and take-off)	Noise, hydrology, geology, visual, air pollution, biodiversity and human health
Runway + buffer maintenance	Biodiversity, hydrology, geology, air pollution
De-icing runways	Hydrology, geology
Fire drills	Hydrology
Runway lighting	Light pollution, biodiversity, visual
Leakage from planes	Hydrology, geology

Methods

Field studies

On-site investigation was made in order to get a deeper understanding on the study area and its surroundings.

Literature review

This EIS is supported by scientific literature research papers.

Case studies

As an inspiration, the work was compared with former impact assessments created for other international airports. The use of case studies was also used when evaluating potential impacts.

Geographical Information System (GIS)

The use of maps is helpful when trying to understand the area of interest. It also gave a visual understanding of the spatial impact of the expanding the airport. GIS is also a useful tool to communicate results toward a broader public.

Checklists

EU-recommendations were followed while creating this EIA. A checklist was created and adhered to as much as possible. This method contributed to a higher efficiency regarding working process by defining clear aims and time constraints to follow.

Matrix

A matrix was used to relate all research results. It summarises the impact assessment and better defines the gravity of each identified impact in a more visually understanding overview.

Calculations

The rational method was used to calculate peak surface runoff. It is a simple approach for estimating peak surface runoff in a given catchment. This method assumes uniform hydrologic losses and that the area is less than 90 acres. When drainage areas become more complex this method tends to overestimate the runoff (Urban Drainage and Flood Control District, 2016).

CLD

A CLD has been created to give a clearer idea of links and feedbacks between elements of our topic. The CLD was based on different scenarios and made connections between each scenario, it was based on all other methods.

2.3 Alternatives

The proposed activity from Swedavia includes constructing a runway on the North-East side of the airport. However, alternatives are available concerning the location, design, use of material and operational methods.

The first alternative of the construction and operation phase of the runways is the zero alternative. Under this alternative, nothing is changed and no runway is going to be built. However, this alternative is not further discussed in this chapter, but it is analyzed in further detail in the next one. Both alternative runways, North and East, are placed parallel to runway 1 and 3, because the purpose of the new runway is the increase of Arlanda's maximum capacity. A runway in another position would not achieve this goal and is therefore excluded from further consideration.

2.3.1 Alternative locations

Western option – Excluded from further assessment

If a new runway is placed in the West part of the airport, it will intersect the highway "E4" and the railway tracks.

For this location to be usable, the current road network and railway in close proximity will have to be redirected, which could prove to be very costly. Also, the amount of noise pollution created by the operation of the runway affects the health of the citizens in Märsta and Upplands-Väsby. It is likely that the noise level restrictions will be violated in the area to the West if a runway is placed there.

Southern option – Excluded from further assessment

Constructing a runway in the South may need some rerouting of the current road network as well as the railway network.

However, the main objection for the Southern option is the noise restriction-levels to the South. There is a high probability that a runway added on that side of the terminal would violate the restrictions in noise levels in Upplands-Väsby.

Northern option – It is assessed further

The Northern option for a new runway provides smaller challenges regarding the disturbance of inhabitants in the area. The reason is that there are less settlements to the North than to the West and South. The main issue of creating a runway in this area seems to be connected to the environmental issues that can arise with the removal of green surfaces and the addition of different types of pollutions. This is especially true concerning the nature reserve Laggatorp. It might be necessary to distance the potential runway in the North from the nature reserve due to the possible disturbance levels in the operational phase.

Eastern option – It is assessed further

There are no insurmountable regulations to the East of the airport that prohibits the construction of a runway. A potential reason for this is absence of dense settlements on the East side. There is no railway in this area but there are roads. However, these are smaller and less travelled compared to the West and South. The main complication of creating a runway in this area seems to be connected to the environmental issues that can arise with the removal of green surfaces and increased pollution levels.

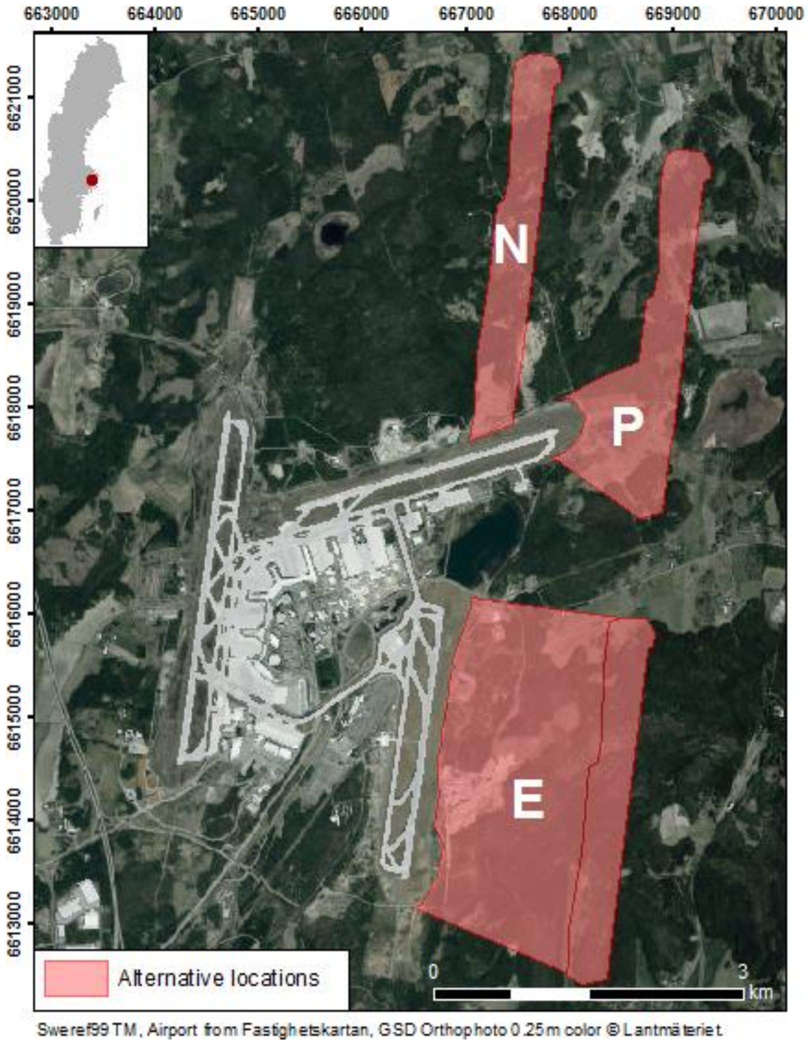


Figure 2.6: Here a map of the alternative locations of the runways is presented.

2.3.2 Alternative designs

Swedavia proposes a runway that supports the landing and take-off of the heaviest and largest aircrafts, which means that the length of the runway should be similar to runway 1. It means its dimensions should be 3.300m x 45m (Airportguide, 2017).

An alternative design would be a smaller runway, as runway 2 and 3, their dimensions are 2.500m x 45m (Airportguide, 2017). This can prove to be the best compromise from an environmental position.

Smaller dimensions represent an interesting alternative because it would reduce the perimeter for noise pollution, have a smaller impact on land use and be easier to fit in the landscape. Swedavia would still be able to carry the heaviest aircraft with the runway 1 and may not need an extra runway to fulfill this purpose.

3.3 Alternative materials

The alternative materials for runways depend on the local ground conditions and the type of aircrafts using it. Arlanda airport currently has three runways; two of them are made out of concrete and the other one out of asphalt. The proposed material of the new runway is concrete based on its better environmental performance. For a major airport, concrete and asphalt are the most common materials used in the construction of runways. For airport with very low traffic flights, it is possible to use grassland and salt flats as runways. Considering that Arlanda airport is the third largest airport in the Nordic countries and that it has high flight movements, it is not possible to choose soft surfaces as runway materials.

Concrete runways are widely used at major commercial airports as it is the most preferable type of pavement for long-term minimum maintenance (Andino, 2015). The runway constructed by concrete is more durable and has a long lifespan, although it has longer construction period than asphalts. The concrete pavement also reflects more sunlight compared to the asphalt. As well as, the concrete pavement releasing less CO_2 emissions on a long term basis (Calhoun *et al*., 2015). One issue with concrete is that when it is exposed to extreme temperatures, it is notorious for cracking.

Asphalt is a more flexible material and the construction of asphalt runways takes less time and has lower costs. However, the problem with asphalt material is the deformation and temperature instability. As the temperature increases, the asphalt becomes softer and more prone to damage. Heavy planes continually following the same routes along runways could cause surface deformation that means the maintenance frequency would be high.

From an environmental impact perspective, there is no big difference between concrete and asphalt. Concrete runways take more time to be constructed than asphalt, but asphalt runways take more time during the maintenance and rehabilitation phase.

Runways have been known as a contributor to noise pollution during construction and maintenance, but in most of the studies concerning life cycle assessment, noise was not formally considered due to a lack of data and appropriate measurement methods (Peeraya *et al*., 2016). Taking into account the life cycle assessment of these two materials, emissions of CO_2 is the main environmental impact. The pros and cons of asphalt and concrete are presented in the Table 2.4. In some cases, different additives can be mixed into asphalt to reduce noise pollutant. One example is the use of bitumen, a rubber material (Nordegren, 2015). However, if rubber is dissolved in water, it could increase the concentration of microplastics, which are toxic to water living organisms (Öckerman, 2016).

Table 2.4: The comparison of asphalt and concrete materials

Materials	Pros	Cons
Asphalt	Short time construction; Noise reducing	High maintenance frequency; toxic additives
Concrete	Durable; long lifespan; less CO_2 emission	Long time construction

2.3.4 Alternative operation methods

For aircrafts to be able to stay on the runway and taxiway, the surface needs a certain amount of friction. When there is ice on the runway, the friction becomes very low and airplanes may skid on these surfaces. Therefore, it is of high importance that these runways and taxiways are cleaned at all time. Most chemicals that are used have one or several drawbacks.

Today Swedavia uses a *PSB* method to deal with snow and ice. *P* stands for plowing, *S* for sweeping it off with steel brushes and *B* for blowing (Swedavia AB, 2017b; Airport Technology, 2010). They also use potassium formate (HCOOK) as a de-icing chemical for the runways while the airplanes are de-iced using propylene glycol. Most of the excess chemicals are collected and shipped to treatment plants as a carbon source. In the future, Swedavia is planning to reuse this after a series of cleaning steps. To deal with tire tracks (rubber residue), they use high water pressure and steel brushes. This is vacuumed by a machine to reduce the load on wastewater (Andersson, 2014).

2.3.4.1 De-icing chemicals

Both chemicals used for de-icing are easily biodegradable and have a low toxicity. HCOOK works under a lower temperatures compared to Urea (-15°C compared to -5°C) (Alatyppö, 2010).

Problems

The problem with both chemicals is that they demand a high level of dissolved oxygen to be able to degrade to CO_2 and H_2O (Alatyppö, 2010; Huttunen-Saarivirta *et al.*, 2011). Dissolved oxygen is also used by flora and fauna in the water, hence a higher TOC value and death of flora and fauna (Hagström *et al.*, 2004). Another problem with HCOOK is its ability to increase corrosion on metals (Alatyppö, 2010). Many products therefore include other compounds to contradict this characteristic. An increase in metals leads to eutrophication (increases the amount of nutrients in the water) and could be toxic, depending on what metal is dissolved in the water.

Alternatives

Urea is an alternative solution for the de-icing because it does not trigger corrosion, but it increases the amount of nutrients that is transported and leads to eutrophication (Huttunen-Saarivirta *et al.*, 2011). Another alternative is *NaCl*, which is cheap compared to HCOOK, but it increases the corrosion of metals very much compared to HCOOK (Huttunen-Saarivirta *et al.*, 2011). A third option is betaine, which triggers less corrosion and it uses less oxygen during decomposition than both $C_3H_6(OH)_2$ and HCOOK (Davis, 2010). On the other hand, betaine does include nitrogen, and therefore causes eutrophication. Another problem with it is that it leaves a residue when it evaporates from water. Sand is another option to increase friction, but it could destroy the mechanical parts of airplanes (EPA, 2000).

Some lab results show that Betaine is less effective for de-icing the runway than formate. Other tests on airfields in Finland showed that the results of both formate and betaine were similar (Alatyppö, 2010).

Alternatives for glycol are still under research. The challenge is to find a chemical that has a low biological impact, low corrosiveness and low oxygen demand during decomposition of organic material. An option that surfaced in 2013, was infrared de-icing but the cost and logistic were an issue (Rosenlof, 2013). Another alternative of using a chemical altogether is to heat the runway. Some options for de-icing the runway include:

- Using geothermal energy (Lopez, 2012; Athmann *et al.*, 2008; Wang *et al.*, 2013);
- Residual heat from an external energy station (Lundberg, 2000);
- Storing energy from solar panels (ICAX, 2017);
- Surging electric energy through electrically conductive (Iowa State University, 2015);
- Spraying nanomaterials to ease up the removal of ice and snow when plowing the surface (Iowa State University, 2015).

Geothermal energy can be an option if the natural ground (soil and groundwater) supports that. There are two examples of airports that are testing heated runways: Greater Binghamton airport in USA (Lopez, 2012), O'Hare airport in Chicago USA (Edén, 2017). According to Magnus Linder who was interviewed by Airport Technology (2010), the esker is already used as a geothermal energy source to heat up the terminals (used as complementary heating). Therefore, it would be safe to assume that the esker has not enough capacity to heat up every runway. ¨

Residual heat demands that there is a power plant in the local area that has excess heat/energy. Using solar panels is an option that needs more research. Large asphalt covered areas absorb a lot of solar energy. Inserting a material that increases the electrical conductivity is an option, however, this still needs to be researched further. One example of this is the De Moines International Airport in USA (Lopez, 2017). The last method, spraying nanomaterials (such as Teflon), is not an option since it is environmentally hazardous.

Conclusively, the use of heated runways could lead to less use of chemicals for de-icing the runways (and taxiways) or stop using it altogether, which would demand less use of treatment plants and less environmental impact. According to earlier research (Edén, 2017; Lundberg, 2000) there is a definite option of implementing this.

2.3.4.2 Cleaning

Problems

The only problem with high pressure water is that it needs to be collected since its goal is to dissolve chemicals which could have an environmental impact.

Alternatives

Other alternatives include using abrasives (sandblasting) and mechanically removing 3 – 5 mm of the surface. The latter would demand higher maintenance of the surface. In other words, reapplying new surface material (Speidel, 2002). Sand, as it was stated earlier, could end up inside airplane and destroy mechanical components.

2.3.4.3 Fire exercise

The main issues regarding fire exercises were the use of old PFAS containing fire foam, and spreading fire fuel at fire drill sites. From 2011 and onwards, Swedavia uses fluorine free extinguishing foam during accidents (Swedavia, 2017d). In Finland, water is used to extinguish fires during an exercise (Finavia, 2016). Swedavia instead uses a detergent dissolved in water during drills. To mitigate the adverse impacts, Swedavia installed a rubber blanket under the runways to be able to collect (and hinder) all spill water to reach the groundwater.

Problems

Since no new problems have arisen, no alternative is needed, but a continuation of cleaning old PFAS is needed.

2.4 Environmental impacts

Identification and assessment of the environmental impacts are the beating heart of any EIA. Chapter 4 presents the significant impacts of the proposed plan and alternatives as presented in chapter 2 and 3. Where possible and necessary, mitigation measures are proposed to reduce the impact on the environment.

Each paragraph discusses one environmental aspect. Firstly, an impact matrix is shown in which the significance of the impact is assessed. All the combinations with a score above or below zero are assessed. Secondly mitigation measures are proposed to mitigate the adverse impacts.

The impact matrix is a qualitative assessment of the predicted impact. It is important to be noted that numbers assigned to the impacts have no quantitative value and should not be enumerated. Also, minor and major may have a different weight in different environmental aspects.

Table 2.5: Impact evaluation – matrix

Major positive impact	++
Minor positive impact	+
No impact	0
Minor negative impact	-
Major negative impact	- -

2.4.1 Noise

Table 2.6: Noise assessment

	Zero	Location			Design		Material		Operational methods		
		P.	N.	E.	Short	Long	Asph.	Concr.	D-I	Cl.	Fi.
Noise (construction)	0	0	0	0	0	0	0	0	0	0	0
Noise (operation)	-	-	-	--	-	-	0	0	0	0	0

2.4.1.1 Impact assessment per alternatives

Zero alternative

According to the Draft Masterplan of Swedavia, the need for a third parallel runway will start to arise between the years 2025 and 2035 and be critical between the years 2030 and 2060. The need depends on the pace of increasing in flight movements at Arlanda (Swedavia AB, 2017c).

Currently Arlanda airport is not working at full capacity and the noise is not spread out to its maximum borders. It is however likely that between the years 2025 and 2060 it will reach its borders. This means that the noise pollution resulting from flight movements will increase and affect more people in the region around Arlanda (see Figure 2.1).

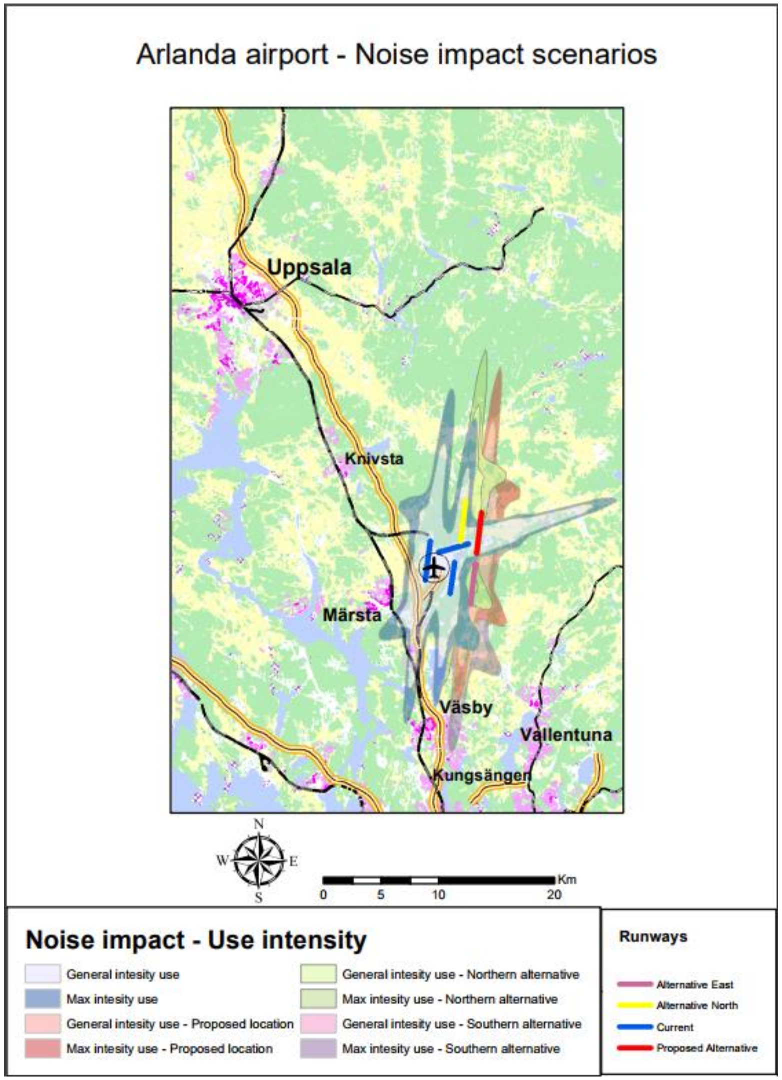


Figure 2.7: Different noise impact scenarios depending on the location of the added runway

Important to note is that it is very likely that the population in the area around Arlanda will grow and that the numbers shown in the alternatives do not represent that growth (Swedavia AB, 2017c).

Alternative locations

Proposed location

This alternative will increase the area exposed to high levels of noise pollution by approximately 41 km^2, which is an increase of 31%. In this case the increase of residential buildings affected is 357. This is an increase of 29% to the situation of today's maximum use of runways.

Furthermore, the borders of the area that would be affected by higher levels of noise will not violate any current restrictions regarding noise as decided by the government (SFS 2004:675). (see Figure 2.7).

Alternative North

This alternative will increase the area exposed to high levels of noise pollution by 22 km^2, which is an increase of 16%. In this case the increase of residential buildings affected is by 122, this is an increase of 10% to the situation of today's maximum use of the runways.

Furthermore, the borders of the area that would be affected by higher levels of noise will not violate any current restrictions regarding noise as decided by the government (SFS 2004:675) (see Figure 2.7).

Alternative East

This alternative will increase the area exposed to high levels of noise pollution by 35 km^2, which is an increase of 26%. In this case the increase of residential buildings affected is by 1121, this is an increase of 91% to the current situation.

Furthermore, the borders of the area that would be affected by higher levels of noise will most probably violate current restrictions regarding noise as decided by the government in the southern direction (SFS 2004:675). This will probably be perceived as a considerable disturbance by the inhabitants of Upplands-Väsby (see Figure 2.7).

2.4.1.2 Mitigation measures

Today there are no additional mitigations measures that can further lessen the noise produced by aircrafts. Noise generated by airplanes originates from their engines and their aerodynamic shape. Mitigation measures for noise cancellation consist of improving those two factors. The resulting mitigation measure is to encourage airplanes that have the newest technology available to the highest degree possible.

To decrease the noise load on the area most affected, it is possible to mitigate by alternating the paths used by airplanes for landing and take-off. By varying fly-paths, one single area will not be getting the full impact of the airplanes.

It is also possible to change the method for the landing procedure, which currently consists of a stair-step descent, to a continuous descent approach. Such an approach seems to not only lessen the noise created by airplanes but also lessen the amount of fuel needed during descent (Girvin, 2009). This method of landing is however not yet recognized as viable, as it seems more research is needed for it to be accepted.

2.4.2 Air quality and climate

Table 2.7: Air quality and climate assessment

	Zero	Location			Design		Material		Operational methods		
		P.	N.	E.	Short	Long	Asph.	Concr.	D-I	Cl.	Fi.
Air quality (construction)	0	-	-	-	0	0	--	-	0	0	0
Air quality (operation)	-	-	-	-	0	0	-	0	0	0	0

2.4.2.1 Impact assessment per alternatives

Runway construction and operation activities have direct adverse impacts on the air quality and climate due to NOx, carbon dioxide and released particles. This paragraph presents the assessment of air quality and climate change associated with different alternatives.

Zero alternative

The zero alternative involves the flight movements increase based on the current infrastructures and no runway will be constructed. In that case, the air pollutants will not be increased by construction activities. However, an increasing frequency in flights movement is observed. This will have adverse impacts on the air quality and climate due to aircrafts emissions. From 2015 to 2016, air traffic has increased by 4% and the landing and take-off emissions have increased by close to 5% regarding carbon dioxide, NO_x and SO_2 (Swedavia AB, 2016). According to this trend, in case of existing fuels and engines does not change, the landing and take-off emissions will increase with 62% by 2040 and 113% by 2070.

Alternative location

The choice of the locations of the runway will not affect the air quality. Though, as long as the new runway is constructed, it would have adverse impacts on the air quality. Even though, the alternative locations have no effect on the total air quality and climate surrounding the airport, the locations will affect the directions of emission spreading. For instance, if the runway is constructed as the proposed alternative, there would be an enhanced effect on the air quality in the surroundings. Because the proposed runway is close and parallel with the runway 3, the emission will spread in the same direction.

Alternative designs

The lengths of the runway have an effect on the quantity of pollutants including dust and carbon dioxide in the construction process. However, the difference of the two alternatives are only 800 meters, this is a minor change in effect on the air quality and climate.

Alternative materials

The negative impacts of the air quality due to concrete and asphalt materials are CO_2, SO_2, NO_x and dust emissions. The emission of greenhouse gases per kilometer caused by asphalt and concrete are listed in table 2.2 (Häkkinen *et al*., 1996). Considering that the construction activity is the temporary activity, the pollutants during the construction process will have a little impact on air quality. During the operation phase, the choice of a concrete surface instead of an asphalt surface would be the best environmental solution. In a period of 40 years, 1.6 km of asphalt pavement releases 7.400.000 kg more carbon dioxide emissions than 1.6 km on concrete pavement (Calhoun *et al*., 2015).

Table 2.8: The environmental burdens between concrete and asphalt paving.

Emissions (kg/km)	CO_2	SO2	NOx	Dust
Concrete	2500	2.6	13	4.1
Asphalt	5000	5.2	26	8.1

Alternative operation methods

The operational methods such as de-icing, cleaning and fire exercises have no direct effects on the air quality and climate.

2.4.2.2 Mitigation measures

Construction impact 1: Dust

On the construction phase, in order to reduce the dust impact, dust control measurements should be implemented. For stockpiling activities, it is recommended that impervious sheets should be used to cover the stockpiling areas (Airport Authority Hong Kong, 2014). In addition, water spraying system should be applied to reduce the dust emissions, in both the construction process and the material transportation process. Water spraying is a common and effective measurement used in construction activities to prevent fugitive dust emission (Dariusz, 2013).

Operational impact 1: GHG emissions

Air traffic is the eminent producer of Greenhouse gas (GHG) emissions at Arlanda airport. CO_2 and other GHG emissions such as methane and nitrous oxide are caused by the combustion of fossil fuels in aircraft engines (ICAO, 2017b). As the flight movements increase, mitigation measures should be taken into account to mitigate the impact. Modern aircrafts with lower NO_x

and hydrocarbon emissions should be used more to substitute the aircrafts with old engines. Besides aircrafts, vehicles on the runway can also produce GHG emissions. Investment in the zero-emission vehicles can also be a mitigation measure to reduce the emissions from vehicles. The airport is therefore gradually replacing its fleet of vehicles with environmentally sustainable vehicles, which will reduce the emission of GHG (Swedavia, 2017e).

2.4.3 Hydrology

Table 2.9: Hydrology assessment

	Zero	Location			Design		Material		Operational methods		
		P.	N.	E.	Short	Long	Asph.	Concr.	D-I	Cl.	Fi.
Water quality (construction)	0	-	-	-	0	-	-	0	0	0	0
Water quality (operation)	-	--	--	--	0	-	-	0	--	-	0

2.4.3.1 Impact assessment per alternatives

<u>Zero alternative</u>

Assumed is that the amount of flights will increase to 380.000 from 234.367, a 62 % increase in 24 years. According to the IPCC (2013), the average temperature will increase by 0.75 °C by 2040. The second assumption is that the amount of flights will increase to 500.000, a 113 % increase, combined with an estimate average temperature increase of 1.2 °C. The changes in amount of passengers have been compared to the year of 2017.

The use of both propylene glycol and potassium formate is dependent on temperature, precipitation (amount and type) as well as air humidity. According to studies by E. Forsberg (2014), Arlanda uses de-icing chemicals when temperature falls under 3 °C. When temperature increases, the need of de-icing chemicals decreases. Propylene glycol will also be affected by the amount of flights. On the other hand, potassium formate will be affected by the number of runways that need de-icing chemicals.

According to IPCC (2013), precipitation and wind will also increase, and due to the increasing temperature will the snowfall decrease. Even though the amount of flights will increase, which results in an increase in use of de-icing chemicals, an increase in temperature would result in a decrease of need of de-icing chemicals.

With an increase in precipitation, surface runoff increases, especially on a surface with little to no ability to infiltrate. This leads to an increased load on the wastewater system (and treatment plant) and storm water system.

To be able to cope with the increase of flights, both runway 2 and 3 needs to be used more. Therefore, the use of de-icing chemicals on those runways will increase, leading to an increase in the load and concentration of contaminants. This increase can be measured as increased conductivity (K+) and depends on changing oxygen levels in *TOC*. Propylene Glycol needs more oxygen to decompose into CO_2 and H_2O compared to potassium formate, as can be seen of the ratios between dissolved oxygen and de-icing chemical:

$$2K^+ + 2HCOOH + O_2 \rightarrow 2K^+ + H_2O + 2CO_2$$

$$C_3H_6(OH)_2 + 4O_2 \rightarrow 4H_2O + 3CO_2$$

Table 2.10: Ratio between organic compound and oxygen.

De-icing chemical:	Chemical/oxygen ratio
Potassium formate	2:1
Propylene glycol	1:4

In other words, propylene glycol demands more oxygen than potassium formate per unit.

More airplanes showered in propylene glycol may also increase the concentration of Cd in wastewater caused by detaching airplane paint. According to Peter Nason (2014) in an investigation made for Kalmar county, Cd is dissolved, unless in really acidic environment or under extremely reducing environment (no dissolved oxygen).

<u>Alternative location</u>

A new runway will change the load of contaminants and volume of water in the system, and hence, where it is transported. To get a better understanding of the water movement look at Figure 2.4, to understand storm water look at Figure 2.9, for wastewater look at Figure 2.10, surface water movement and Figure 2.12 and the aquifer in Figure 2.11 in Appendix I. Based on rain intensity (i), runoff coefficient (C) and drainage area the peak surface runoff can be calculated (for more information go to Appendix-II). These below are based on rainfall during 2016 (SMHI, 2017), even though precipitation will increase in the future, according to IPCC (2013).

If the runway would be constructed at the proposed option, it would increase storm water volume to Sigridsholmssjön in the East. Also, it would affect groundwater and to some extent, surface water, and therefore increase the load of de-icing chemicals, TOC, Cd, and conductivity. Wastewater would pass through existing treatment plant B457, and its capacity needs to be increased to handle the increased load. This area consists of 66 % forest area, 15 % cultivated land and 18% meadow. The amount of surface runoff increase will be in between the other locations.

If a new runway would be placed in at the Eastern option, contaminants would also be transported by ground and surface water (storm water) to Sigridsholmsjön in the East. The wastewater would take the same rout as if the runway would be placed at the proposed location. This area consists of 83% forest area, 10% meadow and 7% cultivated land. The amount of surface runoff increase will be lowest in this area.

North option: contaminants would be transported by groundwater to the esker. The surface water (storm water) would end up in Halmsjön, which would increase the load in Halmsjöbäcken and in the sequent treatment plants before joining with Märstaån. The wastewater would take the same rout as if the runway would be placed at the proposed location. This area consists of 66 % forest area, 18 % meadow and 15 % cultivated area. The amount of surface runoff increase will be highest in this area.

Table 2.11: The amount of surface runoff that would increase if a runway is to be placed in any of the locations, compared to the zero alternative placed in any of the locations, compared to the zero alternative.

Location of new runway	Runoff coefficient	Short runway		Long runway		Zero alternative surface runoff
		Surface runoff (m^3/day)	Relative increase of surface runoff	Surface runoff (m^3/day)	Relative increase of surface runoff	
Proposed	minimum	236	38%	268	57%	171
	maximum	1047	22%	1077	25%	860
North	minimum	199	57%	230	82%	127
	maximum	786	24%	815	28%	636
East	minimum	514	9%	546	15%	473
	maximum	2992	26%	3021	27%	2370

This table shows that the proposed location will cumulate the lowest amount of surface runoff, which is true due to the highest density of cultivated land in contrast to forested areas.

Alternative designs

The difference between a short runway and a long runway is the difference in groundwater build up and use of de-icing chemicals. The impacts of alternative materials of the runway would increase in use of a longer runway.

A longer runway would collect more storm- and wastewater, which would result in a higher load on ditches, drainage pipes and brooks. A longer runway would demand more use of de-icing chemicals and therefore, a higher concentration of pollutants.

Alternative materials

If the runway would be constructed by asphalt, its potential environmental impact would depend on what additives are inserted into the asphalt. If a rubber polymer would be used as an additive or left on the runway as tire tracks (the largest source), it could increase the load of microplastics during surface runoff. These compounds would be transported by water and therefore end up in microorganisms and fishes. Microplastics can transport environmental toxins and are toxic to water living creatures (Öckerman, 2016). The increase of CO_2 (both during construction and operation phase) increases the concentration of H_2CO_3 in water in low temperatures. If dissolved, it leads to a decrease in pH, it could change the availability of fertilizer nutrients and negative effects on aquatic life (Perry, 2003; Utah State University, 2017)

$$CO_2 + H_20 \rightarrow H_2CO_3$$

$$H_2CO_3 + H_20 \rightarrow HCO_3^- + H_3O^+$$

As has been already stated, using concrete on the runway lessens the load of CO_2, but if fractured it releases CaCO3 into water and soil. This would increase conductivity (increase corrosion rate) and increase pH, as well as the potential of increasing CO_2 levels in a long term perspective.

$$CaCO_3 + H_20 \rightarrow Ca^{2+} + HCO_3^- + OH^-$$

$$HCO_3^- + H_20 \rightarrow H_2CO_3 + OH^- \rightarrow H_20 + CO_2 + OH^-$$

Alternative operation methods

If potassium formate and propylene glycol would still be in use, an ongoing monitoring of TOC and dissolved oxygen would be needed to be able to determine the amount of extra oxygen that is being essential. If there were to be a shift to betaine, it would lead to more nitrate and ammonium, which could lead to eutrophication. This is already an old farmland and therefore, extra nutrition are not a good result. Using energy from solar panels in heated runways, (either by warming water or electrical energy through a conductive surface) would decrease the need for de-icing chemicals and its load on water systems.

The only problem with cleaning using high water pressure is if the compounds are not collected afterwards. The result would be an increase of rubber and heavy metals and microplastics in water systems. Particles that would come off could quicker clog up the filters at the treatment plants and sediment the pipes and ditches/brooks.

Possible contamination at fire exercise location and firefighting foam should not be an issue due if the same principles and methods are used that are already in use. The only potential problem would be use of foam at a location where no rubber blanket has been put down into the ground.

2.4.3.2 Mitigation measures

Operational impact 1: Spreading of de-icing chemicals and other contaminants

There are several mitigation methods that are needed, some of which are already in effect. Treatment plants and monitoring programs that are already in use needs to be adapted to handle the increase in water volume and contaminant load. Specifically, cadmium, oxygen level, TOC and other hydrocarbons. A new focus should be microplastics which is one particle that is not mentioned in Miljörapport 2016 from Swedavia AB (2017b).

Depending on where a fourth (and possibly fifth) runway is located new treatment plants need to be constructed to treat the contaminated water flowing East to Sigridsholmsjön via surface- and groundwater.

Geomembrane could be installed to hinder leakage of contaminated water to groundwater (Vectura Consulting AB, 2011). It should be noted that Swedavia already has installed a geomembrane both under runway 3 (can be seen in Appendix I, Figure 2.11) and the fire training site (Swedavia AB, 2017b).

During construction phase, there is a need to apply for a permit for water management since there is a need for drainage of groundwater and storm water. This water will be contaminated by heavy metals, oil and other hydrocarbons, which if not protected could be transported to the esker. During construction, there is a need to construct pumps, culverts, trenches and conduits that transports the water to treatment plants or ponds/dams (BAC, 2007; Karlsson *et al.*, 2012) that filter the water from these contaminants. Limestone could be added if pH decreases too much during construction.

If this is not done, it could hinder a future use of it as a drinking water source. Although the amount of water is defined as low according to SGU (2017a).

Operational impact 2: Changes in volume of water

To be able to deal with change in volume of water:

- Both flow and storage; and
- Both above ground and below ground.

Before construction builders need to assess plan for the future events. Storm water will increase, flooding may occur. Therefore, proper planning and building of drainage pathways that are designed for these changes in water flux should be performed. In 1983, R.C. Heath concluded that pollutants will penetrate deeper into the ground the further they are from the point of origin.

There is also a need of monitoring esker and groundwater flow to be able to mitigate contamination and changes in groundwater flow and level.

2.4.4 Geology

Table 2.12: Geology assessment

	Zero	Location			Design		Material		Operational methods		
		P.	N.	E.	Short	Long	Asph.	Concr.	D-I	Cl.	Fi.
Soil quality (construction)	0	-	-	-	0	0	0	0	0	0	0
Soil quality (operation)	-	+	-	0	0	-	0	0	-	0	0

2.4.4.1 Impact assessment per alternatives

Most of the effects here are correlated to the effects on groundwater, and therefore, some information can be found in the former chapter.

Zero alternative

Due to climate change, the precipitation will increase in the future. This could increase the groundwater level and create more swamps and wetlands, due to more saturated lands. If the precipitation also brings with it dissolved acids, it could lead to leaching of many minerals, greatly affecting the topsoil and vegetation.

The direction and how quick pollutants spread depend on the hydraulic characteristics of the geological profile (rocks and soil). Depending on soil type, pollutants may be adsorbed and delayed until they reach a new type of sediment. A soil with low hydraulic conductivity (such as well-sorted gravel and sand) is the medium groundwater prefer, opposite to clay and bedrock (high hydraulic conductivity).

An increase in temperature could increase the diffusion of pollutants (metals), according to Zaki *et al.* (2017), which is an aspect that needs to be taken into consideration due to change in climate (increase in temperature).

Alternative location

In hydrology and geology, it is assumed that pollutants will travel through zones with the highest permeability and low hydraulic conductivity (Heath, 1983). An area with high permeability also decreases the effects of drawdown when too much groundwater is pumped out of the ground. If too much groundwater leaves the area the cone of depression will be larger and result in a subsidence (Phantumvanit *et al.*,1989 ; USGS, 2000 ; Leake, 2016). According to the bedrock map of SGU (Figure I-4, in the Appendix I), this area is rich in felsic rock, which contains Granodiorite. According to studies made by USGS, high concentrations of Arsenic could be found in areas rich in Granodiorite (USGS, 2003). This affects the proposed and north location the most. During construction it is needed to deal with minerals that could be rich in arsenic. To some extent, it would also affect the Eastern location as well. During operation, the leaching of arsenic into ground- and surface water would decrease. Arsenic is cancerogenic to humans (World Health Organisation, 2017).

Areas in proximity to the esker have low hydraulic conductivity. Therefore, the North location has a high probability of affecting pollutant and groundwater movement. Since sandy till and peat have similar hydraulic conductivity it, the difference lies in the comparison of bedrock and clay. Bedrock consisted of

Granodiorite and Granite has a higher hydraulic conductivity. Therefore, the Eastern area has higher resilience towards changes to the groundwater.

Another good point of preserving clay areas, or placing the runway in an area rich in clay is of its ability to adsorb heavy metals (Visvanathan *et al.* 2007; Deng *et al.* 2013; Fetter, 2001).

<u>Alternative designs</u>
Same result as alternative location, except it is a longer runway and its result would be bigger in that specific area. When water percolates, it brings dissolved oxygen through the earth surface. In a larger area is covered with a concrete or asphalt less oxygen will reach the area below ground. Therefore, less organic material will consume oxygen upon decomposition. It would consume nitrate and sulphate instead. This would increase nitrogen and other NOx gases and decrease the air quality.

<u>Alternative operation methods</u>
The use of potassium formate will increase the load of potassium, which competes with magnesium in the uptake into plants (Eriksson *et al*., 2010). An increase in the metal ion also increases salinity, which would decrease the growth of plants and lead to crop failure.

When formate and propylene glycol decompose into CO_2 it could increase the acidity of the soil (and water). This could lead to leaching of more metals. Cleaning and fire exercise location (and foam) does not affect soil quality.

2.4.4.2 Mitigation measures

During construction phase there is a need to apply for a permit for water management since there is a need for drainage of groundwater and storm water, an example is when SLL (Stockholm county board) applied for drainage of groundwater and cleaning of water and soil during the construction of the new subway line (Mark- och miljödomstolen, 2017). This water will be contaminated by sand and other soil particles. Some of which could contain arsenic and uranium compounds. (BAC, 2007; Jansen, 1988). Geomembranes could be used to filter these particles (Sembenelli, 1990).

There is a need for test if it is possible to infiltrate water in the soil to counter lowering of the groundwater table, and stop a possible subsidence. See mitigation for water on drainage during construction and operation.

2.4.5 Biodiversity

Table 2.13: Biodiversity assessment

	Zero	Location			Design		Material		Operational methods		
		P.	N.	E.	Short	Long	Asph.	Concr.	D-I	Cl.	Fi.
Biodiversity (construction)	0	--	-	--	-	--	0	0	0	0	0
Biodiversity (operation)	+	--	-	-	-	-	0	0	0	0	0

2.4.5.1 Impact assessment per alternatives

Airport activities have negative impacts on biodiversity for the surrounding environment of an airport by reducing its richness and the number of species living in the surroundings. It affects both plant and animal through habitat loss, fragmentation, degradation or reduction, bird striking and disturbance (AEF, n.d.).

Some positive effects can also be observed once the runway is constructed. The long time management of the lawn is favorable for some type of flora species to develop and thrive in the area. Arlanda is for example a favorable habitat for the red listed protected species Field gentian (*Gentianella campestris*) which has its biggest population on the airport (Lennartsson, 2015).

<u>Zero alternative</u>

The zero alternative has the same impact on the biodiversity as the environmental baselines. The only noticeable impact of an increase of the activity of the airport will be more disturbance from movements and activities that have an effect on migration, reproduction and life pattern of animals. Noise will more regularly be a source of disturbance that will affect negatively animals breeding, communication and migration pattern (AEF, n.d.). The zero alternative is however representing the best environmental alternative regarding impacts on biodiversity.

<u>Alternative locations</u>

Extension of an airport can have a direct impact on the natural habitat of surrounding fauna and flora species. The building up on previous green areas deeply modify and make the land unlivable for certain fauna and flora species.

The construction of new infrastructure leads to a habitat fragmentation by restricting animals to forage, breed or migrate because of the installation of fences, roads or the settlement of an area having an intense activity through the landing and take-off of planes. The area built is losing attractiveness for the settlement of plants and animals through the compaction and vibrations on the floor, vegetation clearance, or during the construction phase by the disposal of rubble on the site or land contamination. It constitutes a degradation of the habitat that results in a loss of biodiversity (AEF, n.d.).

The three propositions are located on the track of river flows that represents a potential habitat and source of water for animal. The building of a runway can modify the path of the rivers and disturb ecosystem relying on it, which lead to ecological changes in the area.

Noise disturbance has a negative effect on wildlife in any location where the runway will be build. The flight of aircrafts at low altitudes leads to escape, startle or avoidance behaviours from animals that costs them energy. On a long term basis this will have an impact on their growth and survival. Noise also disturbs the communication between species, damages mammals hearing and can be one of the biggest reasons for some animals to abandon an area. Therefore, most of the disturbance from noise on local fauna is occurring during the first weeks of its intrusion, a decrease of startle reactions has then been observed (RDU, n.d.). Each alternative location will thus have to take into account the possible impacts, as mentioned above.

Proposed

The proposed plan will be built on two valuable areas that will disappear. On the area at the East of runway 2, the valuable area is characterized by open sandy lands hosting a large number of indicator species and butterflies. Three red listed species have been identified in this area, the Common linet (*Linaria cannabina*), the Small blue (*Cupido minimus)* and the Eurasian skylark (*Alauda* *arvensis*) (Ekologigruppen, 2010). Another valuable area will be affected to the North of the proposed plan. This area is representing a natural habitat and shelter for more than 20 different species of animal and plant, among them 1 red listed species of Trifolium is identified.

The location of the runway can also be problematic for its proximity with the lake of Sigridsholmssjön, which is an area of resting and nesting for birds. The proximity of runways near lakes is increasing the risk of strike with airplanes, mainly for the heavier and slow moving ones such as the Western marsh harrier (*Circus aeruginosus*), Whooper swan (*Cygnus cygnus*) or the Common crane (*Grus grus*) (SCAA, 2006). Some aviation agency, such as the Federal Aviation Administration of US, even recommended to have a separation of distance of 1.524 km (5000 feet) of airports from any hazardous wildlife attractant such as lakes (FAA, 2007). Therefore, the proposed runway is planned to be constructed at only 500 m from the lake which can raise a serious problem of cohabitation between airplanes and birds.

Moreover, the closeness of a runway will higher the level of noise disturbance and will make the lake area unlivable for some bird species. The lake is hosting 3 red listed bird species and more than 10 other types of species of birds which could be affected by the location of a new runway so near of the lake (Ekologigruppen, 2010).

Alternative North

The location of the runway in the North will overlap on one valuable area constituted of open sandy lands where one red listed species of Coleoptera is identified (Ekologigruppen, 2010). The location can affect negatively the surrounding other valuable areas, and most importantly the natural reserve Laggatorp that will highly be affected by noise pollution and general disturbance due to the closeness of the activity of the airport, that will lead to a loss of its ecological value. It is representing for example a natural habitat for the Western capercaillie (*Tetrao urogallus*) that would be directly disturb by the close activity of the airport.

Alternative East

The location of the runway at the East will require to cut down a large forest area, that include the area inside the fences at the west. The leveling of the ground and construction of the runway will represent a major deterioration and loss of habitats for both fauna and flora. The area within the fences will be of 7.5 km2, where fauna life will not be allowed to live, so any kind of animal will have to move away from the place. The alternative East will be constructed on top of two valuable areas and it will affect two others that are within the fences of the airport. It means that four valuable areas will be destroyed by the construction of the runway on the Eastern part. One area is particularly important because of the old age of the pines there, that can represent a natural habitat for the Western capercaillie (*Tetrao urogallus*). During the operation phase, the area will be mostly affected by noise pollution that will spread further to the East toward natural areas.

Alternative designs

Alternative of length of the runway has a heavy importance on the impact on biodiversity. The longer and wider the runway will be, the more it will take available lands that would represent a possible habitat for plants and animals. Consequently, the choice of building the bigger runway with the dimension of 3.300 m has more negative impact on the biodiversity than if the runway would have a length of 2.500 m.

2.4.5.2 Mitigation measures

One way of mitigating the problem of bird or animal strike is to reduce the attractiveness of the surrounding areas. Different techniques exist such as landscaping which consist of removing tree or nesting habitat, managing better the waste around the airport to not be a source of food for any animals, use noise and flare guns to keep them away, as well as having falcons in the area of the airport to hunt birds (AEF, 2017). A professional hunter is already working in Arlanda airport to make the place repulsive and minimized the intrusion of animals in the airport area (Swedavia AB, 2017d). Mitigation measures seem applicable only on life protection of animals but no other option seems to appear to reduce the impact of noise and light pollution or disturbance around the area.

Concerning the change of the river pattern, one mitigation measure would be to design new river channels and reroute the flow pattern to minimize hydrological and ecological changes (AEF, 2017).

<u>Compensation measures</u>

The loss of habitat can be compensated by the restoration, creation or translocation of new habitats (AEF, n.d.). For example, by the extension of the natural reserve of Laggatorp in the Northern part of Arlanda, or by creating a protected area on a place where valuable natural sites are already identified.

2.4.6 Human Health

Table 2.14: Human health assessment

	Zero	Location			Design		Material		Operational methods		
		P.	N.	E.	Short	Long	Asph.	Concr.	D-I	Cl.	Fi.
Human Health (construction)	0	-	-	-	0	0	- -	0	0	0	0
Human health (operation)	- -	0	0	-	0	0	0	0	-	0	0

Human health, as mentioned in the environmental baseline, depends on the air quality and the noise.

Impact on human health coming from noise

In a survey concerning the airport expansion of Kuala Lumpur International Airport 2 in Malaysia, according to Sahrir *et al.* (2014), the maximum noise levels of a construction site have exceeded the limit and the reason behind this is the operation of equipment, vehicles and the activities in this period of time. Also, according to the table given in this article, the noise levels at which human can prevent hearing loss is 75 – 85 dB and for interruption of sleep 45 – 50 dB.

Both in the construction and operation phase of the new runway in Arlanda, the noise affects the human health.

Impact on human health coming from air quality and climate

The air quality assessment has been analyzed before. It was found out that the construction and operation phases of the runway will cover the atmosphere with PM10, CO_2 emissions, SO2 and NO2.

According to World Health Organization (1985), particulate matters (PM), both PM2.5 and PM10, include inhalable particles that are small enough to penetrate the thoracic region of the respiratory system. They include respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms. Also, they include mortality from cardiovascular and respiratory diseases and from lung cancer. PM2.5 forms a stronger risk factor for mortality than PM10. Long-term exposure to PM2.5 is related to an increase in the long-term risk of cardiopulmonary mortality. A state of hypercapnia or an excessive amount of CO_2 in the blood can be produced from very high concentrations of atmospheric CO_2 (Van Ypersele de Strihou, 1974), which typically results in acidosis, a serious and sometimes fatal condition characterized by headache, nausea and visual disturbances (Turino *et al*., 1974). The previous phenomena occur when the atmosphere's CO_2concentration reaches approximately 15.000 ppm (Schaefer, 1982).

According to United States Environmental Protection Agency (EPA, 2017), one consequence of breathing air with high concentration of NO2 is irritating the airways in the human respiratory system. Then, this could provide to the organism respiratory diseases, particularly asthma, leading to symptoms (coughing, wheezing or breathing). Also, Latza *et al*. (2009), through a long term investigation, found out that there is moderate evidence that long-term exposure to an annual mean below 40 μg NO2/m3 is associated with adverse health effects.

Short-term exposures to SO2 can harm the human respiratory system and make breathing difficult. The most sensitive group of people are children, the elderly, and those who suffer from asthma. Also, it contributes to death and serious respiratory illness (e.g., asthma, chronic bronchitis) due to fine particles. (EPA, 2017)

2.4.6.1 Impact assessment per alternatives

Zero alternative

As Arlanda airport is not working at full capacity now, the noise is not spreading out the borders being presented in the Draft Masterplan of Swedavia (2017c). Without constructing and operating of a new runway and under the assumption that the flights will increase from 2025 to 2060, the noise and the air quality will increase and worsen respectively and as a result they will affect human health, in the operation phase. On the construction, there will be no impact as it is supposed that no runway will be constructed.

Alternative locations

In the construction phase and in every alternative location, the impact on human health is assessed as minor negative. The reason behind this is that the process of building a runway will produce a significant amount of emissions in the atmosphere coming from the machines. In addition, the noise being produced will affect the life of humans in many ways, for example their work hours and their sleep.

On the other hand, the operation in the proposed location and in the North, will have no impact on human health as there are not residential areas around. But, in the East alternative location, it will affect the cities being in the South part of Arlanda.

Alternative materials

In the operation phase of the runway, there will be no impact on human health concerning the type of material being used for the runway. However, constructing the runway, the impact is assessed as major minor for asphalt as it emits more CO_2 than concrete, which has no impact.

Alternative operation methods

The operation methods being analyzed in Chapter 3 are the de-icing, cleaning and fire exercise. These three methods will not have an impact on the human health in the surrounding residential areas. However, the workers who will spend time doing the operation will be affected but not significantly.

4.6.2 Mitigation measures

The World Health Organization (1985) has identified three main categories of mitigation measures for health effects:

- Mitigation through control of sources (e.g., pollution standards, safety standards);
- Mitigation through control of exposure (e.g., planning requirements, public health measures);
- Mitigation through health service development (e.g., health education, provision of medical services).

Though, in this case, it depends on the mitigation measures being used on noise and air quality. As long as they will be followed, human health diseases will disappear within a certain timeframe.

2.4.7 Landscape and archaeology

2.4.7.1 Impact assessment per alternative

Table 2.15: Landscape and archeology assessment

	Zero	Location			Design		Material		Operational methods		
		P.	N.	E.	Short	Long	Asph.	Concr.	D-I	Cl.	Fi.
Landscape	-	--	--	--	-	-	0	0	0	0	0
Archaeology	0	-	-	--	0	-	0	0	0	0	0

Alternative zero

In case the fourth runway is not constructed, the surrounding forest and agricultural land will remain untouched. The visual impact of the airport itself in the landscape will not change. However, the amount of flights arriving on and departing from Arlanda will increase to the maximum capacity of the current three runways. This will result in an increased frequency of flights over the area, leading to a higher visual impact in the air.

Archeological sites will not be altered because the airport will not physically expand.

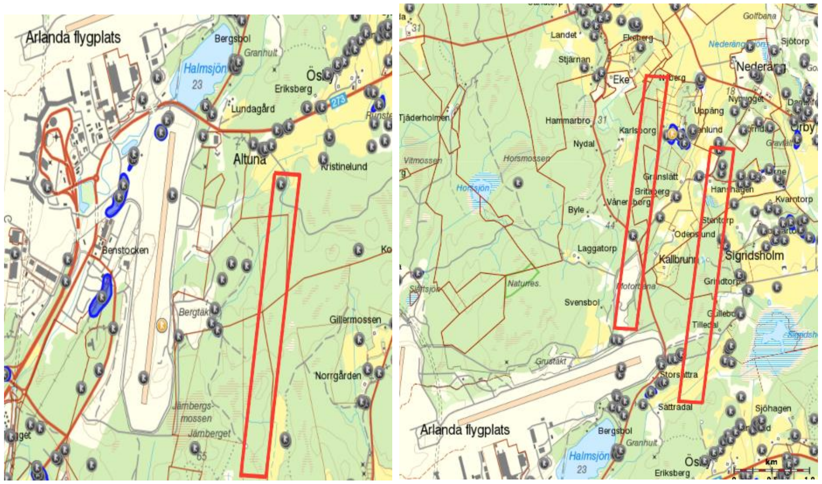


Figure 2.8: Maps with overview of archaeological sites (Riksantikvarieämbetet, 2017)

<u>Alternative locations</u>

Proposed location North-East and alternative North

An increased amount of flight movements will be seen in the air in villages North of Arlanda, among which the hamlets of Vidbo, Botlöd, and Bista. Inhabitants will notice an increase of aircrafts flying over on a lower altitude than they are currently experiencing, increasing the visual impact of the area. Also, users of the International Golf Club will be impacted.

For both the proposed location and the alternative North, an area of between 2.5 and 3.5 km2 of forest and agricultural land will be cleared and converted into airport. This has a big visual impact on the region and will appear as a big bald spot in the landscape.

The proposed location covers at least 5 sites with archeological value. The sites most likely contain traces of early settlement. Archaeological sites need to be treated with great carefulness.

Alternative North is located in an area where three sites of archaeological importance are identified. The sites contain traces of residential and agricultural activity from ca. 1520 AD and graves from the Bronze Age (ca. 1800-50 BC).

Location East

This location affects visual impact of air traffic in a way that inhabitants in the East side of Upplands Väsby will see more aircrafts than they are used to.

The location also involves stripping an area of forest and agricultural land with the size of 7.5 km2. This results in a big empty field in the landscape. However, this is not visible from the built areas or the road, since the houses, roads, and airport are surrounded by forest.

<u>Alternative design</u>

Design and location are inseparably intertwined; the length of the runway determines which area it will cover, and therefore, what area needs to be transformed. However, the difference on the landscape will not be major, considering the differences, because the runway will leave a scar in the landscape, the design alternative solely considers the size of the scar. The visual impact of planes flying over the area is the same in both design alternatives.
Also, noise limitations prevent runway alternative East to be longer than 2.5 km (see paragraph 4.2 about noise impacts).

<u>Construction phase</u>

Both the proposed and alternative locations contain sites of archaeological importance. Archaeological sites will have to be dealt with before the construction starts, read more about this in paragraph 4.7.2 *(construction impact 2: construction in archaeological sensitive areas).*

Construction lights will impact the landscape in the form of light pollution if machines have to work at night. Light pollution can be experienced as disturbing by the direct environment of the construction site.

The landscape will gradually transform from agricultural land/ forest into airport. Levelling soil and cutting trees are main activities that are involved in this process. Piles of wood and soil deposit sites may be a result. However, the construction is temporary and will therefore have no lasting impact on the landscape.

Archaeological value of the environment needs to be taken into consideration during the construction phase. Read more about this in paragraph 4.7.2 (*Construction impact 2: construction in archaeologically sensitive areas).*

2.4.7.2 Mitigation measures

Construction impact 1: light pollution
Mitigation strategies regarding light pollution in the construction phase can be both avoiding and mitigation of effects. By constructing during summer time lights might not be needed and therefore avoided. If it is necessary to use lights they can be positioned in such a way that they will impact the environment to a less extent, or special screens can be used that absorb the light.

Construction impact 2: construction in archaeologically sensitive areas
The most suitable mitigation strategy for archaeological sensitive sites is called *mitigation by excavation, recording and publishing.* Sites marked as archeological sensitive by Riksantikvarieämbetet (2017) should be excavated before the construction begins. Findings must be recorded and published. This process ensures that archaeological findings are systematically and accurately preserved.

Operational impact 1: visibility in landscape
Surrounding the airport with a vegetation edge. The vegetation will block the view from the roads and nearby dwellings on the airport and therefore mitigate the visual impact from the direct surroundings.

Operational impact 2: increased visual air traffic
Using different approaching paths reduces the visual impact of visual air traffic for specific places in the Arlanda region. However, even though the flight paths can vary, there will still be a residual impact which cannot be mitigated.

2.5 Comparing impacts

This chapter presents an overall view of the impacts being assessed in Chapter 2.4. Below, two matrices are shown, one for the construction and one for the operational activities.

Table 2.16: Overall impact assessment in construction phase

	Zero	Location			Design		Material		Operational methods		
		P.	N.	E.	Short	Long	Asph.	Concr.	D-I	Cl.	Fi.
Noise	0	0	0	0	0	0	0	0	0	0	0
Air quality	0	-	-	-	0	0	--	-	0	0	0
Hydrology	0	-	-	-	0	-	-	0	0	0	0
Geology	0	-	-	-	0	0	0	0	0	0	0
Biodiversity	0	--	-	--	-	--	0	0	0	0	0
Human Health	0	-	-	-	0	0	--	0	0	0	0
Landscape	0	-	-	-	0	0	0	0	0	0	0
Archaeology	0	-	-	0	0	0	0	0	0	0	0

Summary	0	--	-	--	0	-	--	0	0	0	0

Considering the above matrix as a whole, the best solution for the runway is constructing it in North. As for the design, making the runway short, the same dimensions as the runway 1, would not have a big effect on the environment. The material that this EIA recommends is concrete, as it does not have a lot of emissions in the atmosphere and does not have an impact on the other parameters either. Last but not least, in the construction phase, all operational methods do not affect the environmental impacts being assessed.

Table 2.17: Overall impact assessment in operation phase

	Zero	**Location**			**Design**		**Material**		**Operational methods**		
		P.	**N.**	**E.**	**Short**	**Long**	**Asph.**	**Concr.**	**D-I**	**Cl.**	**Fi.**
Noise	-	-	-	--	-	-	0	0	0	0	0
Air quality	-	-	-	-	0	0	-	0	0	0	0
Hydrology	-	--	--	--	0	-	-	0	--	-	0
Geology	-	+	-	0	0	-	0	0	-	0	0
Biodiversity	+	--	-	-	-	-	0	0	0	0	0
Human health	--	0	0	-	0	0	0	0	-	0	0

Landscape	-	--	--	--	-	-	0	0	0	0	0
Archaeology	0	-	-	--	0	-	0	0	0	0	0
Summary	-	--	-	--	0	-	-	0	-	0	0

In the operational phase, the zero alternative is the best one. Also, the design of the runway is proposed to be short, as in the construction. The proposed material is again concrete after the assessment being done. Furthermore, the operational method that does not affect either the environment or human health is the fire exercise.

Table 2.18: Impact assessment table

	Zero	Location	Design	Material	Operational methods
Noise	Noise will increase as the air traffic on the airport increases.	The northern location will increase the amount of people affected by noise the least, that is by 16%	No significant impact	No significant impact	Spreading out the approach paths during landing the frequency of disturbance can be spread out over a bigger area. This will affect more people, but they will be affected less intensely than if you had the same approach consistently

Air quality and climate	GHG emissions will increase due to the increase of aircrafts	As long as the new runway propose to be constructed, it would have adverse impacts on the surrounding air quality. There is no difference between different locations.	No impact	Concretes have less adverse impact than asphalts. The dust and CO_2 emissions are the main problem on the construction phase	No significant impact
Hydrology	More air traffic demands more use of de-icing chemicals, but due to temperature increase the use of all de-icing chemicals would decrease. Due to increased surface runoff it need to be applied more often on the runway.	There is no location that is the best. Each one is bad. East and proposed locations would lead to: water transport to Sigridsholmsjön; for the Northern option groundwater would flow to the Esker and surface water would flow to Halmsjön.	A short runway is better due to less use of de-icing chemicals and less surface runoff.	Concrete is better due to less hydrocarbon and microplastic leakage to recipients (compared to Asphalt). The leaching of limestone would be a problem with acidic rainfall.	There are no real alternatives to de-icing chemicals as of now, but research is ongoing and should be monitored. Both regarding heated runways and collecting wastewater.
Geology	Due to climate change more wetlands are a possibility. Higher temperature and more acidic rain would result in an increased leaching of metals from the soil.	The proposed location is the best, since it would have less bedrock with high arsenic levels. Therefore, less leaching of arsenic.	A shorter runway would be better since it hinders percolation to a lesser extent. This would not also increase the possibility of oxygen transport into the soil.	No significant impact.	Salinity load and CO_2 load (acidification) would increase leaching. The quality of the soil would decrease, and nourishments to the plants would decrease.

Biodiversity	Same impact as baselines, best environmental solution	The best environment solution is the runway at the Northern part because it does not affect too much valuable areas and its location is not too close from lakes.	The longer the more it will reduce natural habitat and have an impact on the soil. The best alternative is a length of 2.5km	No significant impact	No significant impact
Human Health	Noise will increase otherwise from the increasing flights and air quality will get worse. These will affect negatively human health	The recommended location is the proposed one and the North. Though the East one will affect human health	No impact	No impact	De-icing operation method have a minor negative effect. Though the other two methods do not affect human health.
Landscape	The visual impact of overflying air traffic increases, but the landscape is untouched.	The proposed location is preferred because it has less impact than alternative East. However, a large area has to be converted.	A length of 2.500 meter is preferred because it has less impact on the landscape.	No impact	No impact
Archaeology	No impact	Location North is preferred because less archaeological sites are impacted.	A length of 2.500 meter is preferred because it is less likely to encounter archaeological sites.	No impact	No impact

2.6 Uncertainty in EIA

Uncertainty is almost unavoidable in EIAs (Tennøy *et al.*, 2006). Decision makers and stakeholders may not be aware of the existence of uncertainties. However, under the construction and operation activities of a new runway, lack of data and the unknown of the future were difficult to deal with. More specifically, the evaluation part could be assessed in a better way if the data was enough. More maps could be created and furthermore evaluation could be done in the human health assessment. Also, the evaluation is considered to be qualitative and not quantitative, which gives a broader perspective point of view.

In the EIA, all the expected impacts on the environment are described using assumptions and the latest insights in impact assessment. Even though the methodologies usually lead to a good representation of reality, they do not offer guarantees that this will happen in the future. Understanding of the actual impacts can solely be obtained using monitoring. In this chapter the knowledge gaps per assessed environmental aspect are presented.

Noise

The prediction of noise impact is impeded and probably somewhat inaccurate due to a lack of program licenses. An extensive noise impact map could not be constructed for this reason. The noise map and all data derived from, it should be regarded with a scrutinizing mind. Furthermore, the weather could be very decisive in where and how much of a disturbance noise (from aircrafts) are. The noise produced by aircrafts can, for example, be muffled by the rain or travel with the wind to affect a lesser/ wider area.

Air quality and climate

The prediction of the air quality and climate impacts was mainly calculated by landing and take-off emissions from aircrafts engines. The emissions effective of the surrounding areas is uncertain, because the spreading of pollutants depends on the temperature and wind speeds and the methodology is also uncertain.

Hydrology and geology

Since the research is still ongoing on some of the chemicals it is hard to make a perfect impact assessment, this is true especially for PFAS and microplastics. Therefore, it is an area of lack of knowledge. As of today we know more of PFAS than microplastics, but it is not enough to say anything for certain. The uncertainty does not only apply to one compound of itself, the cocktail effect (cumulative effect), or how it interacts with other chemicals over time is also hard to foresee. Since the soil is so varied in this area it is hard to make a definitive answer, since the data needed to calculate change in dropdown (subsidence), change in groundwater level, surface runoff etc. are highly dependent on data that are only true on one spot in the ground, with one specific set of variables. Therefore, it needs to be accepted that it cannot be calculated to 100%. To be that accurate more field testing is needed. One example is the mitigation of infiltrating water to hinder a change in groundwater level. Without testing we cannot know if it is even possible. How much water that needs to be drained during construction are impossible to know without testing in situ. Since the use of de-icing chemicals are determined by temperature, humidity, precipitation (amount and type) and wind it is hard to calculate the exact amount needed if just one of these parameters are not perfect. IPCC (2013) has constructed some different scenarios which shows that lack of knowledge (and data) are affecting these estimations. The future changes in fuel of every type of vehicle makes it very hard to estimate future impacts. So therefore we are left with assumptions based on what we know and put forward a best case scenario and a worst case scenario. The calculations of the surface runoff also have uncertainty. The method is a simplistic method since it assumes that the drainage area is consistent. The calculations were done by calculating the runoff for one type of land use and adding it all up afterwards.

Biodiversity

The references are not the most recent ones, most of the text is based on the Naturinventering of Stockholm Arlanda Airport from Ekologigruppen which is an investigation made in 2010. It means that in seven years the state of the biodiversity might have changed.

Human Health

In this EIA, the human health impact is considered to be a unique impact. Though it depends on the noise and the air quality. The uncertainty with it is firstly taking it into consideration as a unique impact. Secondly, one more uncertainty is that no data was used when assessing it. The data to be trusted has to be long lasting and taken by surveys of the hospitals. This was an uncertainty.

Landscape and archaeology

The impact of the fourth runway on the landscape and archaeology is envisioned using maps and qualitative literature research. However, it should be noted that the visual impact of such an activity is susceptible to subjectivity. The presented data is written in a fashion that it entails in an analysis as objective as possible. Nevertheless, users of the area might perceive the impact diversely.

2.7 Conclusion

The executed EIA leads to a recommendation for Swedavia regarding the construction and maintenance of a new runway. The table below presents an overview of the preferred options for both the construction and operational phase combined.

Table 2.19: Best alternative for the new runway

	Location	Design	Material	Operational methods
Noise	North	2.500 meter	-	Diversifying the flight paths to for landing and take-off
Air and climate	North/East	-	Concrete	-
Hydrology	-	2.500 meter	Concrete	De-ice the runway using heated runways
Geology	Proposed	2.500 meter	Concrete	De-ice the runway using heated runways
Biodiversity	North	2.500 meter	-	-
Human Health	North	-	Concrete	-
Landscape and archaeology	North	2.500 meter	-	-

As depicted in the Table 2.19, most categories of impact prefer the Northern option, deviating from this pattern are the impacts on geology and hydrology. The long term impact on geology is lessened/ least if the proposed option is used. The hydrological implications of building a runway in any of the options introduced are all dissatisfactory. In each option there is an impact that worsens the current state significantly. This implies that the impact on hydrology should not act as a deciding factor on where to position the runway. Were that to be the deciding factor, there would not a be a runway constructed in any of the locations available.

The length of the runway is a big factor when interpreting how big of an impact the runway is likely to have. Generally, it is safe to say that the shorter the runway is, the less impact it is expected to have on any of the impact categories presented in this EIA. A shorter runway will impact less of the dwellers in the area by noise. Biodiversity rich areas should also suffer less damages since the runway should destroy less areas of significance. The same reasoning can be extended to the landscape and archaeology, shorter runways should have a lessened destructive impact on landscape and archaeology. Human health as well as air quality needs to be assessed on a larger scale, and the effects on the categories does not significantly change with the length of the runway.

The material used for the runway strip should be concrete since this is expected to have the least impact on any of the categories that are affected by the ground substrate. Noise, biodiversity and landscape and archaeology should remain largely unaffected by the choice of ground substrate between concrete and asphalt. Making the runway 2500 meters or less will open up the possibility to create a runway in the Eastern option significantly, since the impact of noise should not overstep any regulations to the South.

During the operational phase of the runway the best option appears to be heating the track during winter, for de-icing purposes. The best method for doing so is still unclear due to the current early stages of the technology. Doing this will decrease the amount of harmful chemicals that ends up in the surrounding areas, affecting hydrology and biodiversity. Additionally, diversifying the descent and takeoff paths of airplanes will decrease the impact noise makes on the surrounding populace of Arlanda. However, it might affect a larger part of the population.

From the table 2.19, we can conclude that location North is the most suitable location for a concrete runway with a length of 2500 meter. Southerly locations will result in more noise pollution in the region South of Arlanda which will indirectly influence health in that region.

Important to note is that the table above should be interpreted prudently. The preferred alternatives are based on judgement calls made by team members and substantiated by the research presented in chapter 4. Nevertheless, ambiguities should be considered.

Concluded from the preferred design of 2500 meter can be that the smaller alternative has less environmental impact than a runway of 3300 meter. Therefore, the initiator should cautiously consider if the latter is necessary, or if the expected demand can be met with a runway with a smaller size.

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