Global Lakes Sentinel Services

Grant number 313256

GLaSS Training material, Lesson #9

Mine tailing ponds

Where are potentially harmful mine tailing ponds located?

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Lesson summary

In this lesson we will setup a method to locate potentially hazardous mine tailing ponds. World wide there are hundreds of thousands of these ponds, some of them well maintained, others abandoned and not well documented. Yearly large environmental accidents underline the importance of monitoring. The first step is to locate all ponds. In this lesson we will select suitable satellite data, apply masks and include a lot of logical thinking as a first step in setting up a tool to automatically locate mine tailing ponds in large remote areas based on Earth Observation data.

A mining area from above

GLaSS training material outline

This lesson is part of the GLaSS training material. The complete training material outline is listed on http://data.waterinsight.nl/GLaSS/trainingmaterials/GLaSS_lesson_outline.pdf.

Note that the lessons logically follow up on each other, the later lessons might require skills that can be acquired during the earlier lessons.

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List of abbreviations

Abbreviation	**Description**
L8	Landsat 8
NIR	Near Infrared
S2	Sentinel 2
SWIR	Short Wave Infra Red
TOA	Top Of Atmosphere

1 Introduction

1.1 Mine tailings and tailing ponds

Mining activities are focussed on retrieving minerals from the earth's crust, which yield enough economic value on the market. The raw minerals, usually called ore, can differ greater per mine site and may even change in time. There are varying methods for extracting ore from the host material. As a result of mining, impacts in the environment become apparent, resulting from the different processes involved, which depend on hazardous chemicals and modify the surrounding area and the local groundwater systems. The largest by-products resulting from mining are mine water and rock waste. For a large part the by-products are reused into the processing, because of the remaining metal content; the leftovers are stored and distributed (EPA, 2000).

All the water entering the surface of the mine or the underground is called mine water. The water can be stopped at the border of the mining are using different methods and the stopped water can be caught and used for varying purposes. After a mine has become abandoned or production has stopped, water will return to its normal path raising the water level underground and in surface shallows. The composition of the waste products depends on the nature of the waste, which processes have been used, and the chemical composition of the soil, the mine water may still hold heavy metals, other dissolved compounds, have a different temperature and altered pH (Salomons, 1995). After exposure to oxygen, pyrites and sulphide minerals react and acidify the water dissolving remaining metals in the mining area. When mine water runs off into downstream groundwater and surface water it is called Acid Mine Drainage (AMD).

The solid remains after mining are named mine dumps or tailings. These tailings are composed of ground rock and effluents leftover from processes in a mining plant. The extraction of the target minerals is done using a combination of mechanical and chemical processes and results in stream of waste called tailings. The extraction process is not perfect, neither is the reclamation of potentially useful substances. The inextricable and undesired materials, composed of metals, chemicals, process water, minerals and organics are released, most often as a sludge, to a designated storage area, also known as the Tailings Management Facility (TMF) or Tailings Storage Facility (TSF). The composition of most of the slurry differs per mine and substrate characteristics.

Initially, the beginning of the 1900s, tailings were often disposed in local waterways. In some cases the formation of an “upstream tailings dam” was created from the tailings settling on the bank, in a beach-like scene in the stream. After World War II, understanding of processes in the soil improved and dam technology advanced, resulting in more tailing ponds. These ponds were mostly earth-filled or constructed from leftover mining debris. By building an embankment a pond is formed at the start of the mine construction. The pond "walls" are designed to restrain suspended solids. A beach is formed from the tailings, as they are piped in at the crest and the solids are deposited while the water drains away. This beach acts as a buffer between the water in the pond and the dam's wall, these embankments are designed to hold water up till the top. The most dangerous substances are in the water, for example acid, the beach shields the embankment from erosion.

At this time there are methods to store mine tailings on the surface, either in ponds or in piles (dry stacks), or underground in empty mined out areas, usually called backfill. Through storage underground additional support can be provided and ventilation is improved, additionally it can prevent subsidence (EC, 2004). Many parameters should be considered when designing a tailings storage facility. These parameters have a big influence on the optimal site, storage and dispersal methods (Ritcey, 1989). The most important parameters are the environment and the ground composition, these determine methods for tailing control and lead to the design of the facility, the operation and the closure. The unique play between available methods, desired processing and environment result in a specific design. Different technique are suited best for different purposes, to control oxidation of sulphides sub-aqueous disposal, dry stacking or high density thickened tailings can be employed. Current designs take a lot of additional different variables into account, for example: local rainfall, flooding and earthquake chances, seepage and tailings discharge method and rates.

1.2 Environmental challenges of tailings

Due to acid drainage during the lifetime of a mine tailing, tailings can be seen as a potential environmental hazard, in addition there is the risk of a dam breaking, either can lead to leakage of toxic metals, e.g. arsenic and mercury, into the local surroundings (examples can be found in the next section). Often the most important environmental aspect of a mining operation is the disposal of the tailings (Vick, 1990). The volume of tailings can exceed the mined volume, resulting in justified primary focus. The last 100 years the amount of tailings produced has increased significantly. As the market for metals and minerals increased so does the threshold for suitable sites. In addition to advances in technology more and more ore is mined. Over the last 50 years the production has increased from several 10000 tonnes to several 100000 tonnes (Jakubick, McKenna et al. 2003). There are currently single mines producing over 200000 tonnes of tailings per day. At this moment, there are believed to be around 3500 tailings dams of operational mines worldwide.

The increase in production and technology, also increase the challenges for storage. Lower grade ore is accessible through technological breakthroughs, resulting in a bigger volume of waste, leading to higher storage demands. In tandem the environmental regulations are keeping pace, more and better controls are required, with extra attention of storage facilities. The increase in workflow and the need to control it properly increase the pressure on mine operators. As can be seen in the recent incidents with mine tailings the largest part is due to poor management, which in turn results in more stringent control.

The main issue with bad management is often seen as the lack of a financial incentive to manage the waste product properly. The most cost effective approach is often chosen to limit expenses, while meeting regulations. As a results surface impoundments, e.g. dams, embankments, are the go-to method for storage and remain an industry staple. To maintain a dam properly, repairs to reclamation systems and tailings pipes are needed, in addition the water levels in the embankments need to be monitored and the foundation checked for structural deformations. Changes in the sediment movement ate often measured using survey pins. With increased production the mine tailing dams are raised every few years. The design engineers plan out the entire life expectance, can be upwards of 20 years, of a mine and raise accordingly. External inflow into the mine tailing ponds is an additional issue. Diversion channels are included in the designs to keep run-off from the surface out, any water flowing in will be contaminated and has to be treated for metals and chemicals.

Despite advances in technology, allowing for better recycling and more reuse of a lot of waste products at mine locations, the largest part of waste that is untreatable is stored in storage facilities, and management and remediation of these storage facilities is becoming a increasingly large part of modern mine development and mine closure. Ultimately, no solution for tailings is environmentally friendly, consequently miners try to minimize the amount of water in the decommissioning phase to limit the need to long-term management. By covering dry materials and replanting areas the influence of erosion can be minimized, the final design and land formation will limit maintenance after closure. The design of the dam should be sufficient to maintain for at least 1000 years, no matter the natural occurrences, e.g. floods and earthquakes. The amount of abandoned mines is several orders of magnitude higher than the estimated 3500 active tailing ponds dams in the world. In response of a recent spill in the Colorado River, an expert in mine waste treatment explained to National Geographic (Howard, 2015) that just in Colorado, there are an estimated 4650 abandoned mine sites currently leaking toxic waste. There are about 500000 abandoned mines in the U.S., according to the Environmental Protection Agency (EPA). A world-wide number could not be found.

1.3 Incidents with mine tailing ponds

One large incident with a mine tailings dam occurs every year, according to a study by the International Commission of Large Dams and the United Nations Environmental Program (UNEP, 2000). In recent years the frequency of occurrences has doubled. Davies (2002) found the increase in incidents by examining the statistics gathered from earlier periods only matched in the early to mid-1930s.

The main cause for failure is lack of understanding the specifics of the dam technicalities, resulting in issues with the construction of amount of water. Some incidents can be attributes to large natural events, though current designs should take these into account. The largest contributor to mine tailing dam failure is excessive rainfall, where the retention capacity is flooded.

Some examples of accidents:

- Stava, Italy: In 1985, tailings dams built to store waste from fluorite mining failed due to poor design and extreme water pressure. Two hundred thousand cubic meters of tailings flowed more than 4 km downstream at a speed of up to 90 km per hour. The incident killed 269 people and destroyed more than 60 buildings.
- Los Frailes, Spain: Poor design led to a failure in 1998, a 50-meter section of the dam's wall collapsed, sending acidic water containing sulphur, zinc, copper, iron and lead into the Rio Agrio and adjacent farmland.
- Baia Mare, Romania: In 2000, a cyanide spill occurred due to a dam failure. The waste leaked into a local river which discharged into the large Danube River, causing a large environmental disaster.
- Kolontár, Hungary: In 2010, a tailings dam storing waste from bauxite mining collapsed due to heavy rain. The red toxic sludge from the dam spread over eight square km, flooding nearby towns. Ten people were killed, and about 120 were injured. The CEO of Magyar Alumínium ZRt, the company in charge of the dam, was briefly arrested and released after the incident.
- Talvivaara, Finland. Since November 4, 2012 leaked from the gypsum waste pond at the Talvivaara mine in Kainuu to the surrounding rivers and lakes. Only during the first day of the disaster, over 220,000 cubic meters of waste water, containing uranium, sulphate and heavy metals such as nickel and cadmium have leaked away for at least ten days. It is estimated that over 10,000 kilos of nickel and unknown amounts of uranium escaped the mine. A new spill started April 8, 2013 releasing some 350,000 cubic meters of waste waters only within the first day. Talvivaara experienced another leakage releasing some 7,000 cubic meters of waster waters per hour - in total some 350,000 cubic meters are said to have leaked out during the first day. Another new spill started April 7th, 2013. At least 100 hectares of marshland, streams, lakes and ponds have been polluted by the discharges of waste waters. Through heavy application of lime up to a thousand kg of liquid uranium has accumulated as sediment in the grounds and vegetation of the area. At least 20,000 cubic meters of the spill entered in the northern Oulujoki-waterway. The major leak to the south through lake Ylä-Lumijärvi in the major East Finland Vuoksi-waterway included at least 200,000 cubic meters of waste water.

- Mount Polley copper and gold mine in B.C., Canada. The breach of a tailings pond started August 4, and by August 8 the complete mine tailing pond of 4 km diameter was empty. It released five million cubic metres of mining wastewater into local waterways.
- Colorado River, USA. In August 2015 a large spill happened at the Gold King Mine, from which the hazardous material ended up in the Colorado river.
- Brazil, 5 November 2015. The Samarco iron mine dam collapsed and buried the nearby town of Bento Rodrigues with 62 million cubic meters of toxic sludge and killed at least 9 (19 still missing). Next 400 miles of the Rio Doce River was killed before the waste reached the Brazilian coast. By the time of writing this report, tides are expected to spread the substances along a 5.5-mile stretch of coastline, threatening a nature reserve.

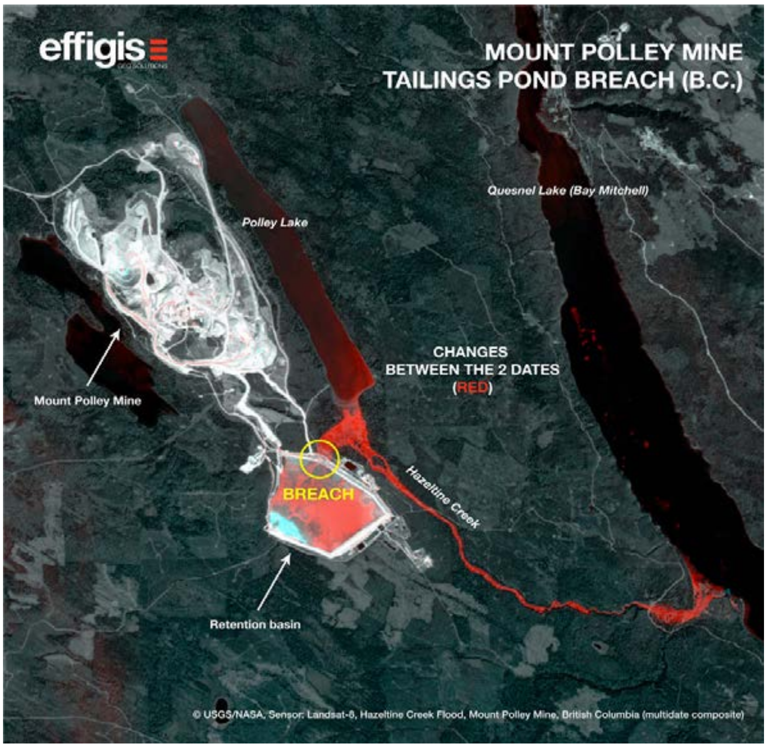


Figure 1. Landsat-8 satellite on August 5, 2014, a day after the accident of the Mount Polly mine in Canada. Hazeltine Creek Creek was originally about 1.2 meters wide and after the incident 150 meters

1.4 This lesson: use of Earth Observation to locate mine tailing ponds

The combination of hazardous waste which can erode its protective dams, the tension between the environmentally storage methods versus the costs, the increasing number of tailing ponds and especially the list of incidents and their effects indicates the importance of regularly monitoring tailing ponds, especially those that remain 'abandoned' after closure of the mines, where management might be lacking.

The conclusion of the characteristics of mine tailing ponds is that they can largely vary in (chemical) content and therefore colour, even for cases where the same ores are mined. Also the structure of the dam(s) and the thickness of the tailings might vary greatly. However, they all contain a combination of water and chemicals. Especially for the abandoned ones the chemicals will be concentrated and therefore show the most pronounced colours. Therefore, Earth Observation might be a feasible method to locate the thousands of abandoned mine tailing ponds, to allow checking these for safety reasons.

To access the impact of mining some work has already been done using EO data. Traditionally the impact of mining is done using ground surveys in chemical, physical and hydrological fields. In research using remote sensing as an aid some progress has been made and successes have reached (e.g., Fenstermaker and Miller, 1994; King et al., 1995). With the appearance of high resolution airborne imaging spectrometry data, such as HYDICE (Rickard et al., 1993), more possibilities become available to assess mine tailing activities pertaining to the environment. AVIRIS data has been used to demonstrate the possibilities to map and monitor the changes in a major silver mining area and base metals mining area. Using a technique called constrained energy minimization the spread of mine tailings on the environment was mapped, as shown by Harsanyi (1993) and Farrand and Harsanyi (1994a). In the study area, the Coeur d'Alene River (CDA) valley in northern Idaho, mining has been active for decades. The sediments in the river and the nearby lake, Coenr d'Alene, have high concentrations of Ag, Cu, Pb, Zn, Cd, Hg, As, and Sb (e.g., Horowitz et al., 1992). The freely available iron oxide binds the trace elements and forms oxy-hydroxide minerals and/or mineraloids. Both adsorption and direct incorporation occur (Schwertmann and Taylor, 1977). Iron oxides, goethite and hematite, associated with acid mine drainage environments according to Ferris et al. (1989), but most common is the metastable mineral ibrrihydrite. The mentioned minerals have characteristic spectra in the VNIR range (0.4-1.3 micrometer), resulting in the potential for mapping using spectrometry data.

Figure 2. Photos of the Colorado spill incident (2015), showing the typical colour of mine tailing water. The river is the Animas River, which discharges in the Colorado. The images on the right bottom show the also affected Doce River, before and after the accident seen by Landsat-8. This image is from remotepixel.ca.

One of the first studies in which EO data was used to locate mine tailing ponds, was performed by Sol, Peters and Aiking (1999), carried out for the World Wildlife Fund. The purpose of that study was to get a first impression of the environmental risk of toxic waste storage in mine tailings ponds in Europe. When it was found that no central database of active or abandoned mines, or relevant international and national legislation existed, a case study using a Landsat Thematic Mapper (TM) image of the south of Spain was carried out to test the option of remote sensing. A combination of high reflectance in the green and in the red band was used to distinguish mine tailing ponds from other waters (that are either darker or at least darker in the red band). This spectral signatures can be explained by the reddish yellow/orange colour tones resulting from acid mine drainage that can also be seen in the photos of the Colorado River accident (Figure 2). Its conclusions that located tailing ponds with earth observation instead of by completing a country-by-country approach towards all stake holders could greatly speed up an inventory was the starting point for the current study.

Meanwhile, more remote sensing techniques have been applied on mine tailings. Kopačková and Hladíková (2014) applied spectral unmixing of hyperspectral data to map the relative abundances of mine water components iron, dissolved organic carbon and undissolved particles. While interesting, such hyperspectral imagery cannot currently be obtained from a complete continent to located tailing ponds.

Tote et al. (2010) present a very detailed report on the environmental impact of mining and the limitations and potentials of EO data to monitor these. They consider the following variables:

- Minerals
- Acid mine drainage and ferruginous materials
- Atmospheric pollution and windblown particles
- Temperature increment due to (underground) coal fires
- The following indirect variables are considered:
- Land use and land cover change
- Vegetation stress
- Contaminated surface waters: sediment load and metal contamination
- Changes in soil moisture and groundwater environment
- Subsidence

Some of these are interesting for our current goal: locating potential harmful (abandoned) mine tailing ponds. Tote et al. (2010) list EO as widely used to trace minerals at the surface. With regard to acid mine drainage, based on the results of Swyze et al. (2000) who used an airborne scanner, theoretically Landsat and in particular ASTER could be used to discriminate between different acid mining drainage minerals based on their reflectance spectra. For contamination of surface waters, Tote et al. mainly focuses on suspended particles in mine water, while for contaminating substances they mention the too low spectral and spatial resolution. Higher resolution imagery such as QuickBird and IKONOS are listed as potential sensors for this subject.

In this lesson we will focus on deriving a practical method that can be applied world-wide, to locate (abandoned) mine tailing ponds.

2 This lesson

2.1 Research question

Where are potentially harmful mine tailing ponds located?

2.2 Training objectives / skills to gain in this lesson

Skills that you will gain in this lesson are:

1. Selecting the best suitable satellite data and processing level for your purpose
2. Setting up a logic approach
3. Using masks

2.3 Required software and data

Software and tools

To complete this lesson tasks, the following tools and software are required or suggested:

- BEAM or SNAP (required, see Lesson #1).

Downloadable files

- GLaSS_Training_Lesson9.pdf
  The main document of the lesson including exercises and questions.
- GLaSS_Training_Lesson9_Answers.pdf
  A document containing answers to all questions proposed in the exercises.
- GLaSS_Training_Lesson9_DataAndTools.zip
  Supplied data and tools, described below.

The zip-file with supplied data and tools contains:

- A folder with three Landat 8 satellite images in .dim format (finland_radiance.dim, finland_reflectance.dim and mongolia_reflectance.dim plus the additional data folders).
- A folder with additional data, which contains:
  - o Two files with the locations of mines: Finnish_mines.placemark and Mongolian_mines.placemark
- A folder with the answer data files, containing the satellite imagery after performing the tasks in the exercises

3 Exercise

Part 1 Choice of data

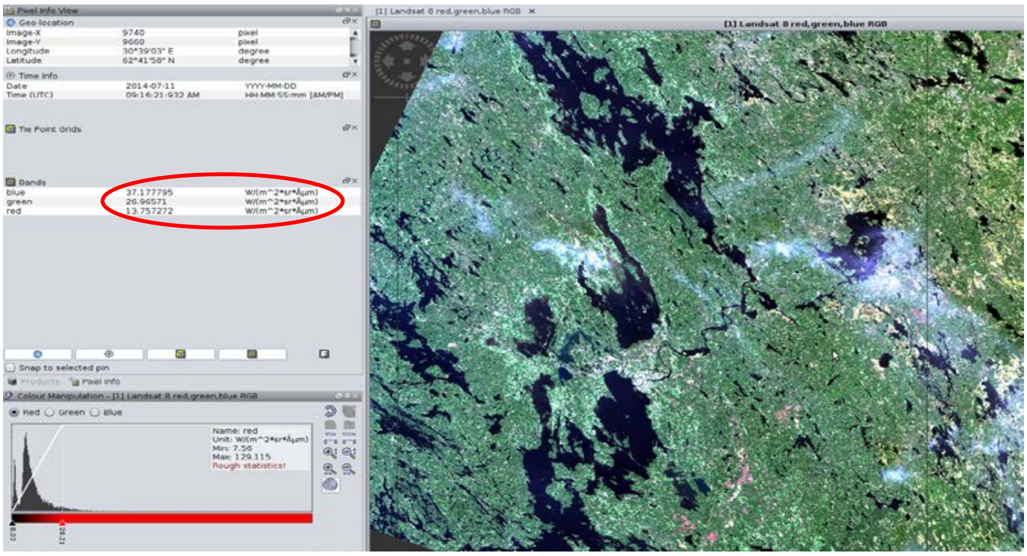
Before GLaSS started working on this, there was no dedicated method to find mine tailing ponds based on EO data. In this exercise you will follow our reasoning to set up a method to locate mine tailing ponds. Therefore, this exercise will include a lot of logic thinking.

Before we can start with our method, we need to agree on the resolution and processing level of the imagery to use. From lesson 4 you will remember the advantages of high resolution imagery and from lesson 6 the disadvantages. In earlier GLaSS lessons you have worked with atmospheric correction.

- Make a logic decision on if it is better to use high resolution or medium/low resolution imagery to locate mine tailing ponds.
  - Think of the requirements to make a choice
  - Check if the disadvantage of your choice can be overcome
- Are there other considerations that have to be taken in account to choose for a specific data source?
- Make a logic decision on working with L1 (TOA – top of atmosphere) or L2 (atmospherically corrected) imagery to find mine tailing ponds. Think of requirements and possibilities.

Now we will have a look at an image of an area in Finland that includes a mine with mine tailing ponds. If you download a Landsat 8 image directly from USGS it will come as “DN” (digital numbers) per pixel per band and meta data that contains the required information to convert these to TOA radiance or TOA reflectance. If you open the original Landsat 8 file in BEAM or SNAP, the program will recognise it as Landsat 8 data and convert it automatically for you to radiance (using the metadata). We have done this and saved the resulting image radiance data as .dim file.

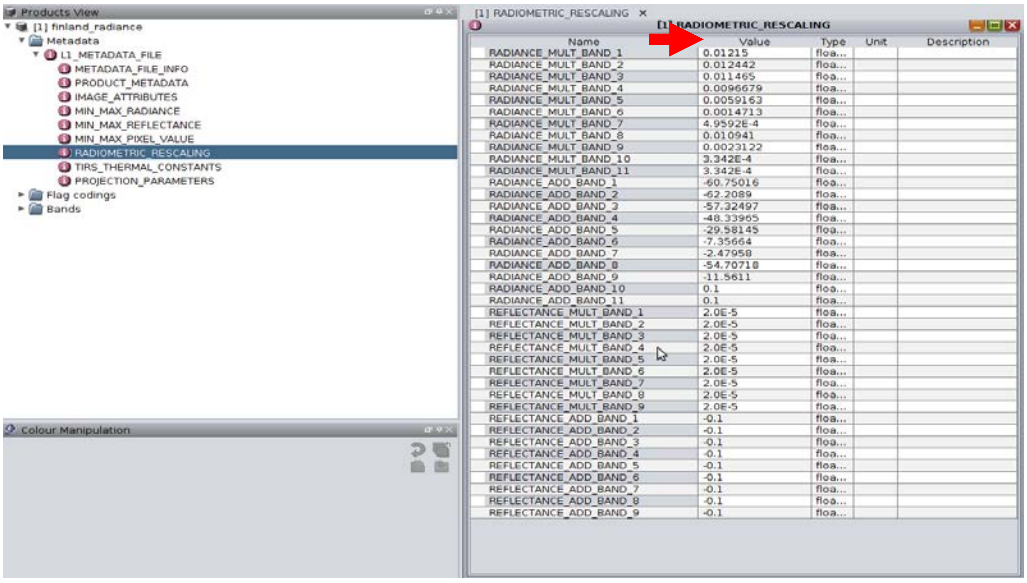
- ➢ Open the image “finland_radiance.dim”
- ➢ Open the RGB image view (select the image in the Product manager – this is the area on the left side of your screen that lists the open products - and use the right-mouse button > RGB image view) to have a look at the area. Can you see the mine tailing pond?
- Go to 'Pixel Info' and move over the image.
- What are the units?



➢ In the Product Manager, open the Metadata folder > L1_METADATA_FILE > double click RADIOMETRIC_RESCALING. In the pop-up window, adjust the column widths so you can read everything

➢ Check out the factors that are provided to convert the original digital numbers (DN) to TOA radiance or to TOA reflectance.

o How would the equation look like to obtain TOA reflectance from an original Landsat file?



To save time, we have done the conversion for you.

➢ Close finland_radiance.dim

➢ Open "finland_reflectance.dim"

➢ Open the RGB image view (select the image in the Product manager > Optical > RGB image view) to have a look at the area.

o Do you see a difference with the radiance data?

➢ Go to 'Pixel Info' and move over the image.

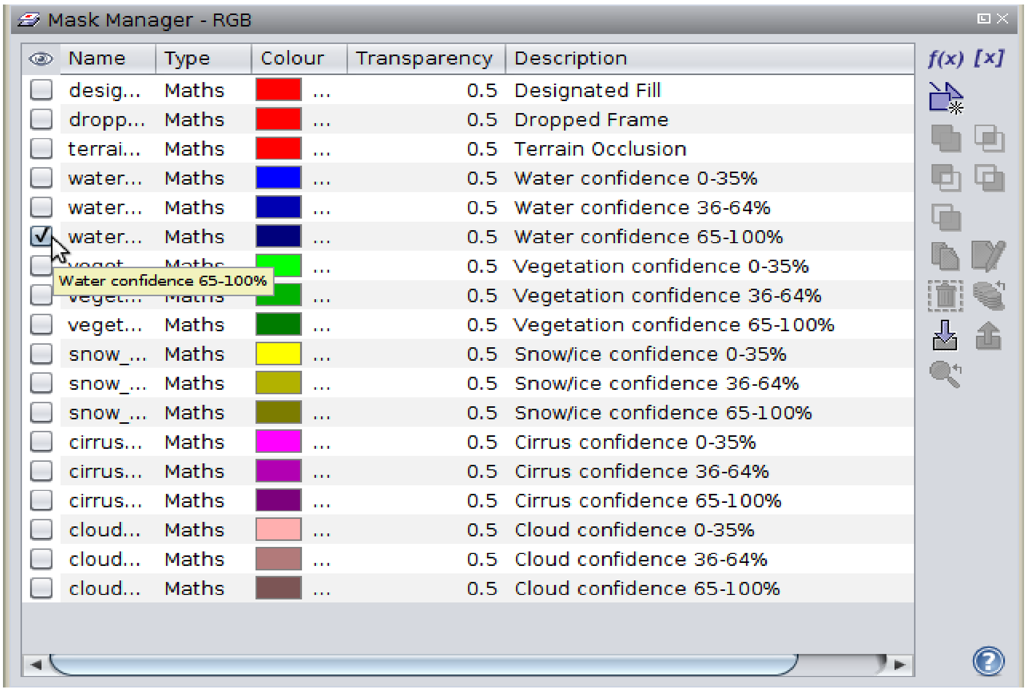
- o What are the units?

Keep this image open for the next steps.

Part 2 Flagging of unnecessary data

Because locating unknown mine tailing ponds in a large area (for example a continent) automatically leads to scanning trough large amounts of images, the first thing to do is removing all data that certainly not contains a mine tailing pond. After removing ('flagging out') these unnecessary pixels, processing would take much less time and computing power. To do this, we will start with the standard 'Masks' that come with a Landsat image. A mask is a data layer that is used to indicate which pixels belong to a certain feature or a certain class. For example, a land-mask indicates which pixels are supposed to be land (value 1) or not land (value 0).

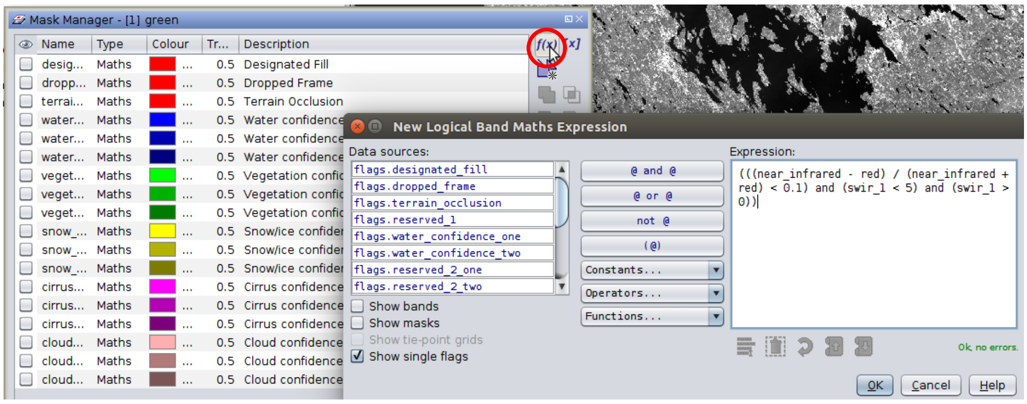
- ➢ To reduce memory space and easier visualise masks, close the RGB image view and instead open a single band in RGB (the green 560 nm band).
- ➢ If we assume a mine tailing pond to appear – optically – as water (although brighter), what would be useful masks to remove redundant data?
- ➢ Open the Mask Manager by clicking on its icon () to list the standard masks that USGS provides for the Landsat 8 data.
- ➢ Check and un-check the boxes one by one to find out if the standard land and cloud masks are sufficient to apply.



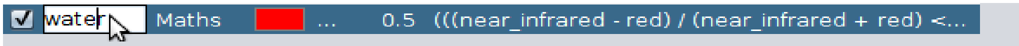
Instead of the standard Landsat 8 masks, we will now apply our own masks.

- ➢ In the Mask Manager, click the function *f(x)* button.
- ➢ Create an alternative mask based on the BC water-equation:

  water = (((near_infrared - red) / (near_infrared + red) < 0.1) and (swir_1 < 5) and (swir_1 > 0))



➢ After entering the equation, adjust the name of the mask.

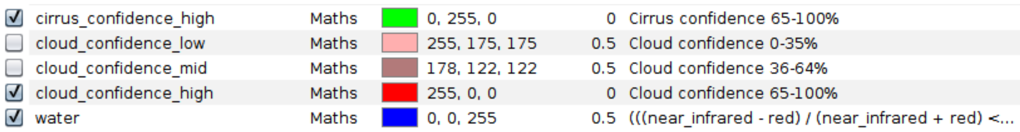


Turn the new land flag / water mask on and off while moving the image to find out where the mask works well or less well.

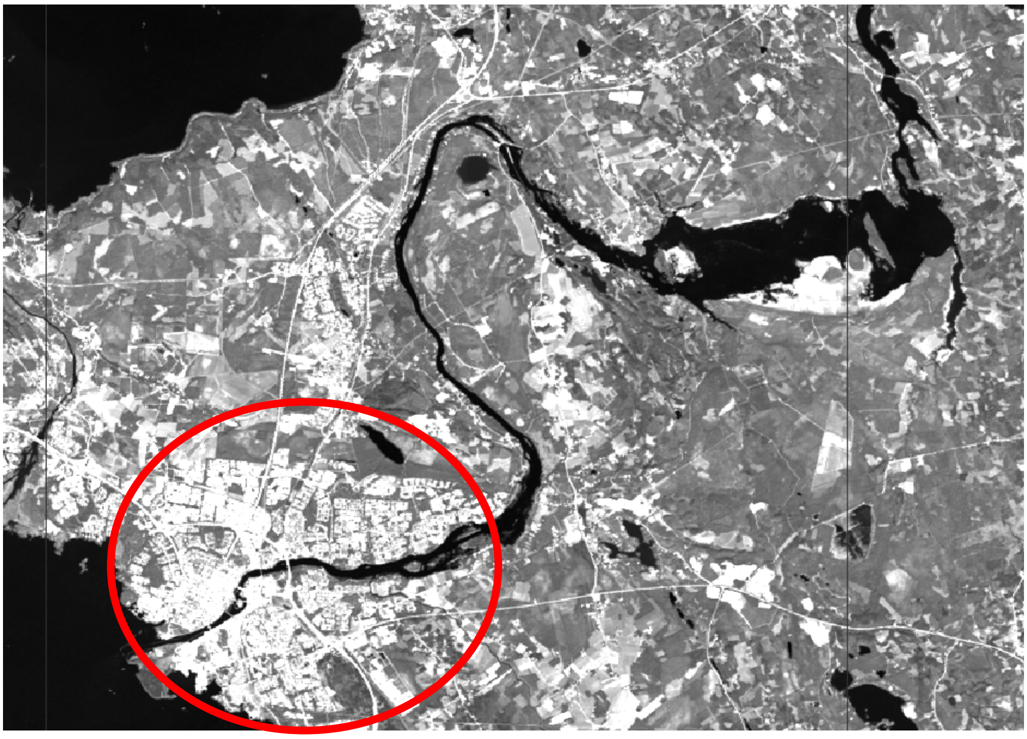
- o Does the water mask generally include the bright or the dark pixels? Does that make sense? Which pixels are interesting for our purpose?

We will now look into the next step of masking/flagging. Because we are especially interested in the bright pixels that still fall within the water mask, we need to properly remove the clouds. (Assuming clouds are also bright).

➢ In the Mask Manipulator, you can change the colour and transparency of masks to make them easier visible. Change the colour of the new water mask to blue, the highest cloud confidence to red and 0 transparency and the highest cirrus confidence to green and 0 transparency.



➢ First check out the area at the south-western end of the largest river in the image (see figure below for the location). In this area the water mask includes bright pixels. Turn the water mask on and turn the cloud and cirrus masks with the highest confidence on and off to see if some of these 'water' pixels could also be clouds. What do you think we are looking at?



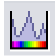
- Next, move around trough the image and turn the highest confidence cirrus and cloud masks on and off.
  - Are there any other areas where bright pixels in the water mask overlap with the high confidence cloud and/or cirrus mask?
  - Do these features look like clouds? Or: in other words, are we properly removing clouds now?
  - Knowing that this area is located in Finland, for which there is very much spatial data available and e.g. mines are very well documented. What could we do to learn more about these locations?
  - Should we apply the cloud flag?

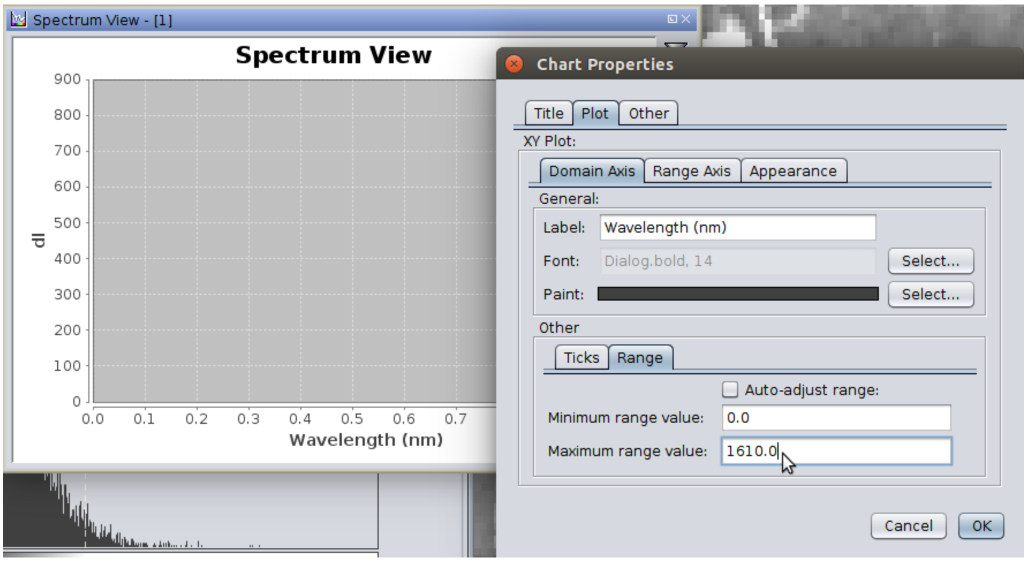
After the last step in the exercise we realised that (parts of) the mining areas, either the bare rocks or the ponds with water on it, might resemble clouds somehow. GLaSS deliverable report 5.6 (2015) includes a more extensive explanation of the Landsat 8 cloud flags, all details are in the handbook (https://landsat.usgs.gov/l8handbook_section4.php). The summary is that Landsat uses a complex structure, calculating potential masks and then applying weighting factors to derive the number given to the quality band (which provides the information for the masks). The original potential cloud mask is calculated based on the Normalised Difference Snow Index: NDSI = (GREEN - SWIR_1) / (GREEN + SWIR_1). From the USGS L8 handbook: “The reflectances of clouds and snow are similar in the green band [...]. However, in Band 6 (SWIR_1), clouds have high reflectivity while snow reflectivity is low. Pixels that fall between an NDSI of 0.25 and 0.7 qualify as potential clouds” (while pixels with NDSI >0.8 get the label snow/ice).

- Make the snow/ice flag yellow and 0 transparent.
- Zoom into the area of the two mines we now know (see answer section) and turn the highest confidence snow/ice mask on and off.
  - Where does the snow/ice mask mask pixels?

- o Could there really be any ice?

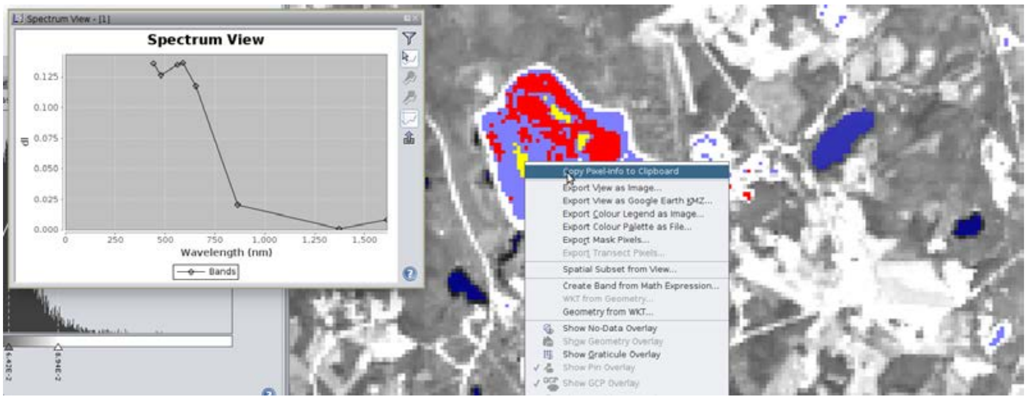
This indicates that mines might also be found using the snow/ice mask. The question is whether this makes any sense. We will have a look at the reflectance spectra to answer this.

- ➢ Open Spectrum View, by clicking the icon () or via the menu 'Optical' > 'Spectrum View'
- ➢ Right-mouse-click the Spectrum View window > Properties > 'Plot' (tab) > 'Domain axis' > 'Range' to adjust the x-axis to the range of the bands we are interested in (0 - 1610). Than go to the tab 'Range axis' > 'Range' > select 'Auto adjust range'. Now the y-axis will auto adjust to the values. > OK.



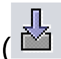
- ➢ Move over the image and look up typical spectral shapes of water of a lake, vegetated land, a relatively thick cloud and one of the pixels that is masked with the snow/ice flag.
- ➢ Check the coastal-aerosol, blue, green, red, NIR and SWIR_1 bands. (Note that in the automatic plot, the panchromatic and cirrus bands will also appear).

- ➢ To make the comparison easier, right-mouse-click the pixels you are interested in via 'Copy to clipboard' put them in another program to plot and compare them.
- ➢ Think of the two equations that have come by so far in relation to the spectral shape:
  - ((NIR - red) / (NIR + red) < 0.1 to distinguish water from land-mask
  - NDSI = green - swir_1) / (green + swir_1) to trace potential clouds (using: 0.25 < NDSI < 0.7) and snow/ice (NDSI > 0.8)
- o Can you now explain why some of our pixels of interest are in the snow/ice mask?



Part 3 Locating mines

Let's use the combination of water according to our own mask, and 'snow/ice confidence high' as a method to locate potential mine tailing ponds.

- Move around in this image to find more pixels that fall in both our water mask and the 'snow/ice confidence high' mask.
  - o Are there more potential mine tailing ponds?
- If you cannot find them, open the Pin Manager (), Import () the locations of the mines (File: Finnish_mines.placemark (in the folder Additional data)) > open

To test if the method works, we will now continue with another part of the world: Mongolia. In contrast to Finland, in Mongolia there is missing information on the location of (some) mines. The area is very large, and next to large mining companies, some mining is also done by hand. You can have a look at this website to get an impression of the Mongolian artisan mine workers http://archive.olloo.mn/News/1219686.html. It is obvious that some of these areas will be not well registered, and on the other hand hard to locate via remote sensing.

- Open the image mongolia_reflectance.dim

We will now try to locate potential mine tailing ponds in this image by following these steps:

- Go to Product Manager and open the green band
- Open the Mask Manager and create the mask that we also applied to Finland:

  water = (((near_infrared - red) / (near_infrared + red) < 0.1) and (swir_1 < 5) and (swir_1 > 0))
- Change the colour of the mask to blue
- In the Mask Manager, change the colour of the snow/ice confidence high mask to yellow and 0 transparency and turn it on
- Move around the image and find pixels where the two masks overlap. You can create another mask for that (water AND snow/ice confidence high), and/or adjust the colour scale of the band you have open so the coloured parts are better visible.
- Check some of the potential mine tailing ponds you locate by looking them up at external sources (e.g. Google Earth and Internet). Do you find mine tailing ponds?
- Look up what can be found at 48.54623 N, 105.27106 E. Is this a mine tailing pond? Explain why it shows up in our combined mask.
  - o Does the algorithm work?
- Use the Pin Manager to open the file Mongolian_mines.placemark (from the

Additional data folder) to see all the mines that were located, the false positives and the false negative that was confirmed.

Part 4 Options for further improvement

In GLaSS Deliverable report D5.6 (2015) you can read that for some other areas (Azerbaijan) the method leads to a large number of false positives.

- Open the image azerbaijan_reflectance.dim.
- Open the green band. As you can see, we have already added our water mask.
- Move around the image to see the areas that show up as water. Is this correct?
- Turn the current water mask off and create a new one, by making the masking more tight:

  water2 = (((near_infrared - red) / (near_infrared + red) < 0.05) and (swir_1 < 5) and (swir_1 > 0))

  - Is the new mask better?
- Create a new combined mask: water2 AND snow/ice confidence high
  - Are the pixels that now show in our mask mine tailing ponds?

Next to this image, it happened in other images that heavy thick clouds showed up with a combination of water and snow/ice, which does make sense when freezing occurs in the clouds. In GLaSS Deliverable 5.6 (2015) a more advanced cloud masking was therefore proposed.

- List options to improve the mine tailing algorithm.

4 More information and further reading

This lesson is based on the following report:

- GLaSS Deliverable 5.6, 2015. Global Lakes Sentinel Services, D5.6: Mine tailing ponds. WI. Available via: www.glass-project.eu/downloads

The report is suggested for further reading. It contains:

- The results of a method for which this lesson followed the main steps. The full method also applies an additional cloud mask and on top of that a binary propagation algorithm to “grow” the pixels that fall within the combined masks back to the original body of water it was a part off. In a final step the body of water is reduced to eliminate mixed pixels at the edges; this is accomplished using a binary erosion algorithm.

For more information on GLaSS, and to download all public reports: www.glass-project.eu.

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Colophon

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Mine tailing ponds

Where are potentially harmful mine tailing ponds located?

Annelies Hommersom (WI), Bram Krommendijk (WI)

2016

GLaSS Consortium

No	Name	Short Name
1	WATER INSIGHT BV	WI
2	SUOMEN YMPARISTOKESKUS	SYKE
3	EOMAP GmbH & Co.KG	EOMAP
4	STICHTING VU-VUMC	VU/VUmc
5	BROCKMANN CONSULT GMBH	BC
6	CONSIGLIO NAZIONALE DELLE RICERCHE	CNR
7	TARTU OBSERVATORY	TO
8	BROCKMANN GEOMATICS SWEDEN AB	BG